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- Promotion of research and development on organization of innovation knowledge in general and particular fields by integrating conceptual approaches to classification developed by artificial intelligence and knowledge management communities,
- International observation, analysis, evaluation and reporting of progress in these directions,
- Promotion on an international level of the exchange of information and experience in the Theory of Inventive Problem Solving TRIZ of scientists and practitioners, of universities and other educational organizations,
- Development of TRIZ through contributions from dedicated experts and specialists in particular areas of expertise.

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ETRIA e.V. - European TRIZ Association
Basler Str. 115
D-79115 Freiburg
Germany
Internet: www.etria.eu
E-Mail: info@etria.eu
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Technology based university spin offs – Why do they succeed or fail?

Kobus Cilliers, Darrell Mann*

Systematic Innovation Network, 9 Olliver Close, Halesowen, B62 0QB, United Kingdom
Systematic Innovation Network, The Old Vicarage, Bideford, EX39 5QW, United Kingdom

* Corresponding author. Tel.: +44-777-333-3338; E-mail address: kobus@kobus.eu

Abstract

The paper reports the results of an intensive 127,000 patent document - study using the TRIZ-based ApolloSigma patent quality assessment tool. The primary focus of the study has been a comparison between industry-originated versus US and UK academia-originated IP from the period 2010 to the present day. The results offer an initial insight into why academia has such a poor track record of monetizing the IP it generates.

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Keywords: TRIZ, ApolloSigma

1. Introduction

According to the globally recognised IP Handbook[1], the average Return on Investment (ROI) on R&D funds spent in UK universities is about 1%. In the US, the figure rises to just under 2%. For every $100 universities invest in research, in other words, less than $2 of tangible benefit is delivered. An argument made by academics when confronted with these figures is that the primary role of academia is teaching and not innovating. Another argument is that universities are intended to act as the inventive sparks that can then be passed over to industry-based commercialization partners. Many governments in the last decade have sought to foster this academia-industry ‘relay’ through the establishment of spin-outs[2] incubators[3] and Knowledge Transfer Partnerships[4]. Thus far there is little evidence to suggest that all of the effort and expenditure has meaningfully affected the innovation outcomes. Perhaps tellingly, the amount of academic analysis of the reasons for the apparently poor performance have been somewhat sparse in more recent past. Nobody, it seems, likes bad news. Especially if, upon deeper investigation, it carries the possibility of even worse news.

In theory, TRIZ should offer some insight into the <2% ROI statistic. The Law Of System Completeness, when applied to looking at ‘innovation’ as a system, for example, should tell us that success requires that six elements need to be present[5]. Even a cursory glance at these six elements should offer some kind of hint as to the innovation challenges faced by any university spin-out: they only really have control over the ‘more ideal product/service’ element. More complex still, the Law Of System Completeness also operates hierarchically, such that each of the six high-level ‘innovation system’ elements also needs to possess a complete viable system in its own right. As illustrated in Figure 1, which illustrates the six essential elements that make up the part of the high-level system the universities, in theory, have under their direct control.

Figure 1: Law Of System Completeness Applied To ‘Innovation’ System
Within this lower level system, the ‘engine’ is the intellectual property. This is the aspect of the overall system that this paper focuses on. In doing so, the authors recognize that the roots of the dismal innovation track record of academia may well be found within any or all of the other elements of the Figure 1 model. An analysis at that level, sadly, is beyond the scope of this paper since it requires case-by-case detailed knowledge of each innovation attempt looking at the market demand, route to market, means of production, coordination and sensor elements. The authors typically conduct such analyses on an individual basis for individual clients, such that we know anecdotally why and where attempts tend to go wrong.

This paper focuses on the IP ‘engine’ part of the story, then, partly due to the ability to analyse large quantities of data with ease, and partly because, it should then, partly due to the ability to analyse large quantities of production, coordination and sensor elements. The authors looking at the market demand, route to market, means of by-case detailed knowledge of each innovation attempt sadly, is beyond the scope of this paper since it requires case-

The primary tool that has been used to conduct the evaluation is the proprietary ‘ApolloSigma’ capability developed within the Systematic Innovation Network following requests from client organisations to be able to more meaningfully measure the quality as well as the quantity of patents being generated by an enterprise. The next section of the paper describes the – TRIZ-based foundations of the ApolloSigma calculation method. Following that, the paper reports the results of an analysis of 127,000 patents that have been analysed using the ApolloSigma tool, and then ends with a short series of preliminary conclusion and recommendations for the academic community in general and the university-lead technology-company spin-out community specifically.

2. ApolloSigma – Measuring IP Quality

Ever since organizations have been subject to legal obligations to report the value of their intangible assets, a seeming industry of IP valuers has emerged. Understandably, in any industry, the initial ways in which value are measured are crude. Quite sensibly in the case of IP, the manner in which, for example, patents are filed lays open many decades of historical data that can be used to build ways and means of correlating between IP holdings and financial value. Thus it was found that there is a strong correlation between the number of times a given patent is cited by other later patents in the same industry domain and the value of that patent. Almost all IP valuation methods thus become focused on this kind of historical analysis.

Given the inevitably slow patent process, the citation process is only able to start one or two years after a patent is filed. And then, because patent lawyers use a rigorous classification structure, a link between one patent and another is only deemed relevant if the two exist within the same internationally agreed classification codes. The big problem this in turn causes is that it completely fails to take into account that nearly every disruptive innovation comes not from a current competitor with an R&D team inventing solutions in a race with yours, but from someone outside your industry who realizes that their solution better serves the functional needs of your customer. The detergent industry, to take a likely up and coming example, busy citing other detergent patents, will be disrupted by a textile industry player that creates self-cleaning fabrics.

The IP valuation industry is built on not just inadequate but the wrong foundations. From a business strategy perspective it is no wonder that the IP function is almost completely divorced – no leader can sensibly run their business with data that is two years out of date and blind-sided to disruptive threat. A patent deemed to have a multi-billion dollar value one day may overnight become worthless when a disruptive jump occurs, but the IP valuation team won’t know it’s happened until long after it is too late.

Back in the year 2000, we initiated a research programme to overcome these inbuilt and fundamental problems with the IP valuation industry. Our focus was on building tools and measures for the strategists in the boardroom. Our motivation was to enable leaders to answer the following questions:

1) How much is my IP portfolio currently worth?
2) How will its value change in the coming months and years?
3) What are the disruptive threats that could appear from other industries, what impact could they have on mine, and what do I need to do about it?
4) What are the possibilities for me to exploit my existing IP into other industries?

In simple terms, it was all about giving leaders the ability to drive their business by looking through the windscreen rather than the rear-view mirror.

As it happens, fifteen years after the start of the research, the past can do a lot to help us to predict the future. Study over five million innovation datapoints, as we now have, and you begin to see that the future is very highly predictable. Or rather it is provided the story is split into two parts: where and when. Knowing when a given technology jump will happen in the future is very difficult, but knowing where is governed by directions that are as close to laws as we’re ever likely to get. Importantly then, if we know the where, we have the possibility to create the IP that gives us much more control over the when. Let’s have a look at both sides of the where/when story in more detail:

3. The Future ‘Where’

One of the simplest ways to spot patterns in the evolution of technical systems is to arrange solutions that deliver the same function in chronological order. The following example shows what happens when we do this for a computer keyboard (Figure 2):

Figure 2: (Predictable) Evolution Of The Computer Keyboard
Another example does the same for the function cutting. Each of the stages shown in the chronological progression represents a step-change evolution in the delivery of the function. And while the systems on the left of the progression might still exist, the value very definitely migrates from left to right, with, at each stage, some kind of conflict having to be solved. So, in the evolution of ‘cutting’, the various stage jumps in turn tackle problems of speed, accuracy, tool-wear and flexibility of use/elimination of waste.

Repeat this kind of analysis a few thousand times and a pattern very clearly emerges. It looks something like the Dynamization trend known well by anyone in the TRIZ community (Figure 4):

It is a trend describing how technical systems become progressively more ‘dynamized’. It turns out to be one of thirty eight (so far) other similar trend patterns, each describing a different aspect of how systems have evolved. The big advantage this offers is that if we take our own system – say we are designing the wing of an aircraft – and see that it is not at the end of the trend, then we immediately have a good idea where it is likely to evolve in the future. Aircraft wings are currently a ‘jointed system’ (second stage of the trend) and are thus highly likely to jump in the future to a ‘fully-flexible’ system. We can say this with some certainty because, the trend tells us, tens of thousands of other systems have solved conflicts and been successful by making exactly the same jumps.

When we examine a given system – like a wing – relative to the other trends that the research has uncovered, we can very quickly derive a snapshot view of how far that system has evolved in terms of some kind of universal ‘evolution potential’ measure. In our research, we tend to draw such evolution potential maps in the form of a radar chart:

4. The Future ‘When’

Knowing where things will evolve in the future represents a good start in terms of an IP valuation capability, but in order to give sensible strategic information, we also need to be able to acquire an objective means of assessing the when. The outcome of our research into this timing question has revealed two key factors:

a) How quickly the industry has been jumping in the past, and,
b) How many hierarchical levels exist between the current system type and a future ‘ideal’ state.

We can examine the second of these two by looking at how the forces of competition drive all industries towards more ideal solutions. The following example, Figure 6, examines evolution within the laundry industry. On the left of the picture are the three main industry players together delivering the function ‘cleaned clothes’. On the far right hand side is the ultimate solution – the function gets delivered (i.e. the clothes get cleaned in this case) with zero cost and zero negative side effects. The ultimate solution – except if you earn a living making detergent or washing machines – is that the clothes clean themselves. The moment consumers are convinced that such a solution actually works, inherently there is no place for either detergent or washing machines anymore. In such a world – which, thanks to the competitive pressures within the textile industry, is not too far away – the future value of detergent or washing machine IP rapidly tends to zero.
The main point here is that, as illustrated by the cone in the picture, system evolution is convergent, and in a convergent world there are inevitable losers. And moreover given a choice between detergent, machine or textile, it is extremely clear that there is a hierarchy with textiles at the top, then machines then detergents. A washing machine that cleans clothes without detergent is likely to displace even the best detergent, just as, in turn, even the best washing machine will not prevail over a self-cleaning textile fabric. As is usually the case, the threats to an industry tend to come from outside the industry.

It is relatively easy to construct this kind of conical evolution map for any industry in order to establish the hierarchy of winners and losers. What we still haven’t worked out at this stage is when a player is likely to take-over a player lower down the hierarchy. The timing calculation is long and involved, depending to a high degree on the whims of the end customer. We can, however, make a significant step towards the timing answer by examining the rate at which an industry has been making jumps in the past.

The way we do this involves the evolution potential concept again. Only to obtain timing information, it is necessary to see how quickly systems at each hierarchical level are making jumps along each of the trends:

5. Towards A Future-Focused IP Quality Measurement Capability

The above TRIZ-based tools and measurement methods provide an objective means of calculating the likely ‘where’s and ‘when’s of an industry and the IP held within that industry. The calculation, however, still requires a deal of creative thought and involved analysis. A typical analysis for an IP family will take around 4-6 weeks to answer the questions detailed earlier in this paper. The process is made possible thanks to having a database of five million radar plots and previous analyses, but it is not exactly an interactive analysis that permits live scenario planning activities to take place.

In order to solve that particular problem, we have built a number of fully automated IP value assessment algorithms built on the findings accrued from the five million datapoints. Because the measurement needs to be future-focused rather than historical, we have deliberately ignored the traditional measures of IP quality like citations and classifications. Instead, we have built search tools that take advantage of evolution trend information like the earlier ‘dynamization’ trend. By searching through the IP database looking for key words like ‘joint’, ‘flexible’, ‘pneumatic’, ‘field’, etc it is possible to rapidly assess the maturity and number of jumps that a current solution hasn’t made yet.

The output from the machine assessment measures IP against two important dimensions; the first looking at its current strength; the second looking at future potential:

Current Value Index – in this dimension we mine, for example, patent text looking for key-words that make the solution easy to circumvent (thinking about the Dynamization trend shown in Figure 4, ‘immobile’ would be an example of such a word). We have also identified a number of other correlating ‘strength’ factors such as number of independent Claims, length of Claim text, presence of quantified data, etc.

Future Value Index – this dimension very specifically uses the aforementioned trend keywords, such that words like ‘immobile’ are ‘bad’ and words like ‘field’ are ‘good’. We also make a semantic search looking for function words in order that we can establish a hierarchical position of the IP under investigation relative to a universal hierarchy of functions. The resulting output is typically plotted as follows:

The plot divides the IP world into four distinct domains:

Duds – these are the solutions that deliver little or no value to the organization either currently or in the future, and as such are candidates for not spending more money preserving.

Rembrandts – are solutions that have little current value, but have potentially high value in the future due to the possibility that the technology may be transferred to other domains, or the solution is likely to take over the function of something lower in the universal function hierarchy.
Blindsiders – these are simultaneously the most valuable of an organizations current assets, but due to their low future value index are the ones most likely to blind-side an organization to future disruption by alternative technologies or higher level functional solutions.

Stars – these are the solutions with both a high current and future value index. These are patents that are particularly well written and have anticipated as many of the future trend jumps as are achievable with current capabilities.

The main purposes of the output is to first of all benchmark the IP of different players within an industry, or within a certain function. Looking within the portfolio for an organization, it is then aimed at providing portfolio management information – which are the things that can be dropped, ring-fenced or nurtured for example. Because the analysis is forward looking, its biggest value comes when used in conjunction with the trend information. In this role, it becomes possible for inventors and IP generators to assess the Future Value Index of a patent application before it is submitted. In this way, a piece of IP with a low score can be identified early and the inventor is able to look at the un-exploited trend jumps and determine which should then be incorporated into the invention disclosure.

6. Results

ApolloSigma analyses of three separate groups of innovators have been conducted or the specific purpose of this study. The first group is based on multi-national companies with a reputation for technical innovation; the second group focuses on some of the US universities with a reputation for innovation; and the third then focuses on UK universities that also purport to have a specific innovation focus. For each of the three groups, the paper has used US and ‘World’ granted patents as the first evaluation lens. We have chosen this lens since 70% of the world’s IP is filed in the US and to all intents and purposes, is the biggest signal spin-out inventors can give that they are serious about their innovation intent.

Table 1 presents a summary of the first group the paper analysed, the MNC community (see Appendix).

The four columns on the right hand side of the table examine the ApolloSigma scores for each of the companies analysed. One thing that immediately shows up in this Table is the low proportion of patents falling in to the ‘Stars’ category. The average of 0.27% for the ten ‘innovative’ companies analysed is some way below what should be expected based on the way the overall ApolloSigma engine has been calibrated. Were we to analyse the 74 million plus patents that currently exist in the world, we should expect the engine to place around 3% of them in the Stars category.

With this 3% figure in mind, the ten companies analyzed are operating at around 1/10th of the expected average rate. The only ApolloSigma figures that really stand out from this Table are 3M’s relatively high ‘Stars’ score – still below a global average, but five times better than the other organisations included in this study. A deeper dive analysis into this result provides a hint that 3Ms best patents, compared to the other nine companies featured, involve invention at the materials and ‘molecular’ level.

The other stand-out number is the high proportion of ‘Rembrandts’ coming from Samsung. While we are unable to make a meaningful correlation between their patent output and the high number of TRIZ-trained people within the organisation, one might expect that if TRIZ is being proactively used within an organisation, it should be reflected in an assessment method based – as ApolloSigma of course is – on TRIZ trend evolution directions. This result may merit a deeper investigation beyond the scope of this paper.

Separate from the ApolloSigma results, the middle column of Table 1 takes a high-level view of the average number of employees required to generate each of the company’s patents. The overall average being a shade over 33. The stand-out number from this calculation would appear to be Google – who have on average only needed 7 employees to generate each of their patents over the course of the last 6 years.

Table 2, meanwhile, shifts the focus from industry to US Universities (see Appendix).

In relation to the number-of-people required to generate each patent, we see that the average for the ten universities included in the analysis is about three times more than for industry. We have deliberately included students in this calculation since the student population, although primarily present at the university to learn, are an inevitable resource when it comes to intellectual capability. Take the students out of the equation and the average number of employees required to generate each patent shifts from 93 to 48, a figure that starts to get close to the industry average.

From and ApolloSigma perspective, the US universities do rather better than the 3% global average of ‘Star’ patents. They also have a significantly higher proportion of Blindsiders and a lower proportion of Rembrandts.

Finally, Table 3 shows the equivalent IP results for the exemplar UK universities (see Appendix).

The immediately most striking result emerging from this picture is the average number of people required to generate each patent – close to 20x the number of their US equivalents. Take out the students and the 1678 number drops to 362, but that is still 8times lower than the equivalent US figure. Also, perhaps tellingly, the UK figure has become significantly worse in the last six years when compared to the period from 1976.

In terms of ApolloSigma results, the UK distribution between Stars, Rembrandts, Blindsiders and Duds is not far different from those observable from their US counterparts. Figure 9 compares the results from all three groups analysed for this paper:
Examination of this picture from the university spin-out perspective, the positive message would appear to be that academia does rather better than industry (and slightly better than the overall global average) when it comes to generating ‘Star’ intellectual property. Given that the primary role of academia – and especially the universities included in the analysis here – is to push the boundaries of technology, this shouldn’t be too surprising. The fact that this ‘Star’ potential translates to so little tangible ROI is then the bigger mystery.

One that again takes us back to Figure 1 and the boundaries of this study: Star IP is not translating to ROI because of other aspects of the Law Of System Completeness innovation system model.

What still sits very much within the scope of our study here, however, perhaps offers some significant additional clues. Why is it, looking at Figure 9, that academia is generating so many less Rembrandts and so many more Blindsiders than their industry-based equivalents? This seems to be a very big question indeed.

Blindsiders are patents that have a high current value but low future value. They are, in other words, patents that have a very short shelf-life because they are so easy to design around. Our ten exemplar MNCs seem to be very good at weeding these Blindsiders out of their portfolio. Or, more likely, when they identify a piece of IP that starts generating a positive ROI, they invest some of that return into strengthening the IP into a portfolio…

…a perspective re-affirmed by the relative high proportion of Rembrandts. These being patents that are not necessarily generating revenues in the short term, but in the long term they are both difficult to design-around, and are consistent with the evolution directions suggested by TRIZ.

7. Conclusions & Recommendations

It is still early days for this kind of forward-looking IP measurement tool, and as such the algorithms are still being optimized over the course of a series of client engagements. Even in its current form, however, we believe that it already delivers previously unheard of levels of strategic capability to leaders. Just as we might not like what we see when we look through our windscreen, it has to be a better way of driving than spending the whole time looking in a rear-view mirror.

As stated from the outset of this paper, the ability to translate IP into innovation (‘ideas into invoices’) depends on much more than the quality of the IP itself. That said, when we look at academia’s IP quality in comparison with the sorts of portfolio being generated by industry, the authors believe we have identified a significant IP challenge for academia: too much of the IP being generated that starts to generate a useful ROI is extremely vulnerable to design-around from any player that understands the TRIZ evolution trends. Academia, to put it more starkly, is writing poor quality patents, and failing to mitigate for the risks this generates by failing to create portfolios of surrounding IP that helps overcome the low future-proofness of the original IP.

By way of an example, as a part of the research conducted for this paper we looked at the emerging world of graphene, a strategically important core technology that looks set to profoundly affect a host of different technology areas. Graphene was first created in 2004 at one of the UK universities in the cluster we included in our analysis (Manchester). Table 4 shows patent grants with Claims pertaining to graphene since 2004:

<table>
<thead>
<tr>
<th>Graphene Patents Issued as on 28 July 2015</th>
<th>Number issued</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>577</td>
</tr>
<tr>
<td>USA</td>
<td>352</td>
</tr>
<tr>
<td>South Korea</td>
<td>115</td>
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<tr>
<td>Japan</td>
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<td>China</td>
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<tr>
<td>France</td>
<td>6</td>
</tr>
<tr>
<td>Netherlands</td>
<td>6</td>
</tr>
<tr>
<td>UK</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: Graphene Patent Grants Since 2004 Discovery In The UK

The single UK graphene patent (a ‘Blindsider’ in our analysis – no surprise) has now in effect been ring-fenced and/or superseded by the rest of the world (industry mainly – see Figure 10). This hasn’t stopped the UK Government investing over £60M in the last couple of years to construct graphene research facilities. The research will thus continue, no doubt to the benefit of all of mankind, but the ROI will very likely not be there. Now maybe – just maybe – doing something solely for the good of mankind is a valiant and noble venture. Maybe it’s not important to ‘own’ the IP? But the question of should we or shouldn’t we is moot. It’s not an either/or choice. It is perfectly possible to embark on valiant and noble ventures and patent along the way. Just because you own a patent doesn’t prevent you from ‘giving’ your solution away. Owning the IP means you have the
choice to give it away or not. Owning well-written, future-proof IP gives you the best choice of all. That probably isn’t the only important missing piece in the academia-sparked spin-out, but it seems to us to be a pretty good start point.

Figure 10: Graphene Patent Owners (courtesy PatentInspiration)

References
4) https://connect.innovateuk.org/web/ktp

Appendix

Table 1: Summary Of MNC IP Quality For Ten Leading Technical Innovators

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<td>397,592</td>
<td>10.4</td>
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<td>6.8</td>
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<td>25.06%</td>
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<td>187,000</td>
<td>64.4</td>
<td>24.3</td>
<td>74.54%</td>
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<td>338,875</td>
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<td>16.0</td>
<td>74.54%</td>
<td>24.05%</td>
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Average 33.3 16.2 71.56% 27.24% 0.93% 0.27%

Table 2: Summary Of US University IP Quality For Ten Leading Technical Innovators

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<th>Universites - USA</th>
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<th>No patents since 1976</th>
<th>Students</th>
<th>Employees</th>
<th>Total</th>
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<tr>
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<td>5,678</td>
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Average 93.5 28.2 66.99% 13.40% 16.27% 3.35%

Table 3: Summary Of UK University IP Quality For Ten Leading Technical Innovators

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<th>Universities - UK</th>
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<th>No patents 2010-2015</th>
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<th>Students</th>
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<td>33,618</td>
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Average 1678.1 585.3 66.87% 13.40% 16.27% 3.35%
TRIZ-based Modelling and Value Analysis of products as processes

John Cooke*a*

*Cocatalyst Limited, 30 Salisbury Road, Farnborough, GU14 7AL, UK

*a Corresponding author. Tel.: +44 796 6920 595; E-mail address: john@cocatalyst.com

Abstract

TRIZ enables the functions of a technical system to be defined, modelled and improved. During TRIZ system modelling, it is common to describe a product as a device which interacts with an unchanging "target". The reality can often be different, however, as many products effect a sequence of changes in their “target” through the course of their operation. For these cases, it makes much more sense to use TRIZ methods to model the product as a process. When combined with the value optimisation framework presented by the author in a previous paper and used in conjunction with other TRIZ tools and concepts, this form of product-process modelling provides new insights into the effectiveness of a given product design as well as revealing strong directions for its improvement. Although a generic example has been used to demonstrate the method, the product-process modelling approach described has been successfully applied to a number of real world products.

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Keywords: Value Analysis; Functions; Process Analysis

1. Introduction

After its initial development in the 1940s by Laurence D. Miles, Value Analysis is now used by many companies to optimise the value of their products. Enhanced value ideally results from a combination of worthwhile enhancements to products functions and reduced cost in areas which are less important to the customer. A key difference between traditional cost analysis and value analysis is the focus of product function rather than hardware. According to Miles, functions should be defined using two words, a verb and a noun, for example “contains liquid” for a drinking cup. In his process, the value of a product is determined by analysing its functions and then comparing their relative importance to the customer (functional worth) with their cost (functional cost) [1].

Over the last 70 years, the basic method devised by Miles has evolved into an 8-step “Job Plan” which now provides the structure for most Value Analysis projects. Value Analysis is now often viewed as a team-based rather than individual activity. The Value Analysis team follows a number of steps, answering different questions at each stage. Figure 1 summarises the key questions which are addressed at each step.

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Fig. 1. The Value Analysis “Job Plan”
Working on the development of TRIZ, Genrich Altshuller also focused on function and value, for example developing the breakthrough concept of the ideal system [2] which provides a vision of an optimal value solution. Over the following years, the TRIZ community continued to evolve new ways to map and rank functionality [3] and even developed methods to model the underlying physics of a system [4].

2. Functional modelling Methods

The result of activity in the fields of Value Analysis and TRIZ, not to mention other related areas such as Systems Engineering and Lean means that there are many different ways to model the functionality of technical systems. In the next section various product and process modelling methods will be outlined and compared.

2.1. Types of functional mapping applied to products

The Value Analysis method relies heavily on a good understanding of product functions and their relationship to each other. Traditionally, this has been achieved through a range of function modelling methods. In the field of Value Analysis the most broadly accepted way to model the functions of a product is by using a FAST (Functional Analysis System Technique) diagram. The functional descriptions in the FAST diagram concentrate on what the product does rather than its specific design. Any mention of “hardware” is discouraged and each function is structured in verb + noun format. A tree structure is used to show the functional hierarchy of the product [5]. Figure 2 shows an example of a partial FAST diagram for a hand torch. Higher level functions are on the left and lower level functions on the right. The dotted lines show the scope boundaries for the analysis.

![Figure 2: Partial FAST diagram for a hand torch (flashlight)](image)

In the field of Systems Engineering, functionality is often represented using FFBD (Functional Flow Block Diagram) models. The purpose of an FFBD is to indicate the sequential relationship of all functions that must be accomplished by a system. When completed, these diagrams show the entire network of actions that lead to the fulfilment of a function. As with the FAST diagram, FFBDs are function oriented, not equipment or hardware oriented. In other words, they identify “what” must happen and do not assume a particular answer to “how” a function will be performed. FFBDs are developed from the top down to create a hierarchical view of the functions across a series of levels, with tasks at each level identified through functional decomposition of a single task at a higher level. Parallel and alternative operations are shown by using logical AND and OR symbols. FFBDs are particularly useful when complex systems are being analysed [6]. FFBDs are generally used to develop, analyse, and flow down requirements. FFBD modelling helps expose alternative ways to deliver a specific function and is sometimes used to support Value Analysis of a system in a similar way to the FAST diagram. An FFBD can be described as a functional process model for a product. Fig. 3 shows an extract of a FFBD for a hand torch.

![Fig. 3. Partial Functional Flow Block Diagram for a hand torch (flashlight)](image)

Compared with the two previous methods, the functionality of a product is analysed in TRIZ in a significantly different way. In TRIZ “device” function modelling, the physical actions which take place between the various components of an actual product design are mapped [3]. In other words, the product hardware and its functionality are modelled together. Fig. 4 shows a TRIZ “device” function map for a hand torch – harmful actions have been omitted for clarity. In this diagram, system components are shown in rectangles, super-system components are shown in hexagons and the target is shown in a rounded rectangle. In the context of Value Analysis, this modelling approach offers some potential benefits as it enables the hardware costs to be related to functions far more directly than is possible with the more usual subjective allocation methods used in Value Analysis [1].
2.2. Type of functional analysis applied to processes

Processes can also be described hierarchically and physically, in a similar way to the FAST diagram used for products. A process function tree or FAST diagram differs from that of a product in the following ways:

- Any process is made up of a number of operations or steps.
- Each operation can comprise a number of functions.

Fig. 5 shows a partial function tree for a CNC machining process used to manufacture a machine-turned part. The operations are listed in sequence from left to right.

Processes can also be modelled using other methods. Aside from the more general process mapping techniques used in Lean such as Value Stream Mapping, the specific physical functionality of a process can be modelled using TRIZ [7]. One key difference from the TRIZ function map is that in TRIZ process mapping, the “target” of the process undergoes changes as it passes through the various process operations. This means that the TRIZ model of a process often looks somewhat different from that of a product. Fig. 6 shows a partial map of the physical actions in the CNC machining process, using the same shape convention as for TRIZ function modelling - i.e. the target (aluminium tube) is shown by using a rounded rectangle form. As with the product analysis, this diagram only shows useful actions.

When the TRIZ-based methods are used it is possible to simplify the usual Value Analysis “Job Plan” to create a 6-step TRIZ Value Analysis process – see fig. 7. As previously mentioned, much of the traditionally subjective functional cost allocation can now be by-passed.

3. TRIZ-based Value Analysis of case study system

3.1. Why model products as processes?

Many products act as processes in that they effect a sequence of changes in their “target” through the course of their operation. When such a product is analysed using the standard TRIZ “device” function map (as shown in Fig. 4), the true functionality of the product can become distorted and confused. This misrepresentation of system functionality can lead to inaccurate conclusions. In the context of Value
Analysis, inaccurate outputs may cause the wrong elements of the system to be cost optimised. To illustrate this point the “device” and “process” approaches will be used in the TRIZ-based Value Analysis process (as shown in Fig.7) to analyse a case study system – the water heating unit shown in fig. 8.

3.2. Step 1: System description and study scope

The water heater uses a thermostatically controlled electric emersion heating element to raise the water temperature. The tank of the water heater is made from a stainless steel fabrication comprising a cylinder closed off by two end caps and fitted with two wall mounting brackets. Water passes into and out of the tank through two stainless steel tubes welded into the lower tank end cap. Water flow from the tank is regulated by a control valve. The tank is insulated by a layer of PU foam and there is a neon indicator to show that the heater is working. This Value Analysis will study the full tank assembly as described but will ignore any other up-stream water supply and post delivery systems. Product packaging and final test will be included in the study scope.

3.3. Step 2: Information gathering

A critical element of any Value Analysis is the quality of the information used. Cost data should be trustworthy and up-to-date and process information should be comprehensive. Consistent rules should be used to deal with issues such as the way capital cost is accounted. In the case of the water heater, a detailed cost study has just been done, taking into account all the contributory factors including consumable parts, service costs, inventory, machine time, and operator rates. Fig. 9 shows the cost summary for all the items detailed in the water heater bill of materials. All the costs for assembly and test have been allocated to the components of the water heater system listed below.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot tank</td>
<td>$ 6.66</td>
</tr>
<tr>
<td>Inlet pipe</td>
<td>$ 1.30</td>
</tr>
<tr>
<td>Outlet pipe</td>
<td>$ 1.75</td>
</tr>
<tr>
<td>Heating element</td>
<td>$ 2.26</td>
</tr>
<tr>
<td>Wall brackets</td>
<td>$ 0.29</td>
</tr>
<tr>
<td>Thermostat</td>
<td>$ 2.45</td>
</tr>
<tr>
<td>Valve</td>
<td>$ 1.83</td>
</tr>
<tr>
<td>PU foam</td>
<td>$ 1.24</td>
</tr>
<tr>
<td>Neon light</td>
<td>$ 1.80</td>
</tr>
<tr>
<td>Outer casings</td>
<td>$ 1.91</td>
</tr>
<tr>
<td>Packaging &amp; test</td>
<td>$ 1.78</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$ 23.27</strong></td>
</tr>
</tbody>
</table>

Fig. 9. Cost breakdown for water heater

3.4. Step 3: Functional description

Up to this point the content of the Value Analysis steps has been identical for both the “device” modelled and “process” modelled system. At this stage in the analysis, the two approaches start to diverge, leading to widely different results during later stages of the method. Fig. 10 shows the “device” function model for the hot water system. For clarity, only useful functions have been recorded.

The device model of the water heater provides detail on the physical interactions between the components of the system and super-system but fails to highlight any time-based transformations which may be happening to the system target.
When the “process” functional model for the water heater is generated, it becomes apparent that there are two distinct operating conditions for the water heater. These result from the two states of the dispense valve; open or closed. These have been shown by use of logical OR symbols as used in FFBD modelling. In addition, it can be seen that the target undergoes at least one transformation within each of the two operating regimes. Fig. 11 shows the complete “process” functional model for the water heater. Harmful actions have once again been omitted for clarity.

Fig 11. Process functional model of water system with dispense valve closed or open.

3.5. Step 4: Component Worth Analysis

3.5.1. “Device” Function Ranking

The next step in the TRIZ-based Value Analysis process assesses the relative importance of each system component by reviewing their physical actions. In TRIZ, the function ranking method [8] is commonly used to compare the worth of product functions in order to prioritise candidates for trimming. In this section a brief explanation of the method will be shown using a generic example, after which the approach will be applied to the “device” function model to support the Value Analysis of the water heater case study.

In function ranking, system functions (the physical actions performed by each of the components in the system) are first classified. If any action directly acts on the system target it is described as Basic (B). If an action is directed to another system or super-system component it is classed as Auxiliary (A). The auxiliary actions are further ranked according to their proximity to the overall system target. For example, if a component acts on another component which delivers a basic action, if is ranked A1 (auxiliary 1). If a further component acts on the previous component, that action is ranked A2 (auxiliary 2) and so on. If a component acts on a super-system element, the action is ranked A1 (auxiliary 1). The function map in Fig. 12 shows a generalised example of this classification scheme.

Once all the actions have been ranked, each is assigned a numerical value. The following rules are applied:

1. The action with the lowest rank (highest auxiliary number) is scored as 1.
2. The action with the next highest rank is scored 2 and so on.
3. Any actions classified as basic are given a score 2 points higher than the A1 actions.

Fig. 13 shows the scores assigned for the generic example using these rules.

Fig. 12. Generic example of TRIZ function ranking

Fig. 13. Generic example of action scoring
The component rankings are now derived by adding the scores for all actions performed by each component. Fig. 14 shows the component ranking system applied to the generic example. Once the ranking has been calculated, it can optionally be converted onto a standardised weighting scale such as 1-10.

<table>
<thead>
<tr>
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<td></td>
<td>Component 2</td>
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<tr>
<td></td>
<td>Component 3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Component 4</td>
<td>2+1=3</td>
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<tr>
<td></td>
<td>Component 5</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 14. Component ranking example

Applying the same method to the water heater “device” function map (fig. 10) leads to the component rankings shown in fig. 15. Any actions which interact with water (the system target) are ranked as basic.

<table>
<thead>
<tr>
<th>Item</th>
<th>Actions</th>
<th>Class</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
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<td>Hot tank</td>
<td>Holds water</td>
<td>B</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Holds inlet pipe</td>
<td>A1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Holds outlet pipe</td>
<td>A1</td>
<td></td>
</tr>
<tr>
<td>Inlet pipe</td>
<td>Holds water</td>
<td>B</td>
<td>4</td>
</tr>
<tr>
<td>Outlet pipe</td>
<td>Holds water</td>
<td>B</td>
<td>5</td>
</tr>
<tr>
<td>Outlet valve</td>
<td>Holds outlet valve</td>
<td>A2</td>
<td></td>
</tr>
<tr>
<td>Heating element</td>
<td>Heats water</td>
<td>B</td>
<td>4</td>
</tr>
<tr>
<td>Wall brackets</td>
<td>Holds hot tank</td>
<td>A1</td>
<td>2</td>
</tr>
<tr>
<td>Thermostat</td>
<td>Controls electronics</td>
<td>A2</td>
<td>1</td>
</tr>
<tr>
<td>Valve</td>
<td>Controls water</td>
<td>B</td>
<td>4</td>
</tr>
<tr>
<td>PU foam</td>
<td>Insulates hot tank</td>
<td>A1</td>
<td>2</td>
</tr>
<tr>
<td>Neon light</td>
<td>Informs user</td>
<td>A1</td>
<td>2</td>
</tr>
<tr>
<td>Outer casing</td>
<td>Protects user</td>
<td>A1</td>
<td>2</td>
</tr>
<tr>
<td>Packaging &amp; test</td>
<td>Protects system</td>
<td>A2</td>
<td></td>
</tr>
</tbody>
</table>

Fig 15. Water heater component rankings – derived from “device” function map

This analysis shows that the hot tank has the highest importance as a result of the number of different actions it performs. Other components, such as the thermostat rank low because they are delivering only one secondary auxiliary action.

3.5.2. “Process” Function Ranking

The approach used to assess component worth from the process perspective is similar to the device based method but introduces additional concepts and prioritisation methods. There is a greater focus on the actions performed on the target, on the different operating conditions of the system and the level of target transformation delivered by each process operation. As discussed earlier, the process functional analysis showed that the water heater has two distinct operating modes – dispense valve open and dispense valve closed. In order to understand the contributions of each system component, the function map can be re-drawn showing each operating condition side-by-side as shown in fig. 16.

Fig. 16. (a) Process function diagram for water heater in “no output” condition; (b) Process function diagram for water heater in “output” condition.

From the user’s perspective, it soon becomes clear that the “output” condition of the water heater is far more important than the “no output” condition. This insight will be used to help prioritise system functions and components.

Two further tools will now be applied to enable a comprehensive component prioritisation. Firstly, the same function ranking rules as used in the “device” model will be used to categorise the various actions performed by the system components in fig. 16 as basic (B) or auxiliary (A1, A2). Secondly, the actions delivering the process operations will be reviewed using process functional classification.

Process functional classification provides an objective way of assessing the relative importance of different process operations. In this method, each operation is reviewed and classified. The classifications are used to assign a ranking to the operations. Process functional classification can be used to assist in finding the functional worth of each process operation [5]. The table in Fig. 17 shows the different types of process operation and their relative value. Examples are included of each type of operation in the context of a manufacturing process.
Fig. 17. Process functional classification of operations in descending order of importance.

Whereas these process classifications have been traditionally applied to manufacturing processes, they will now be used together with function ranking to classify the actions being performed by the system components during the two conditions of water heater operation – see fig. 18.

Fig. 18. Water system component actions categorised by function rank and operation type

A scoring scheme can now be applied to establish the process functional worth of each of the hot water components. Following the general rules established during function ranking, it is possible to develop various scoring schemes. In real Value Analysis projects it is important to sense check the logic used so that the scoring scheme is prepared with reference to the end user and other key stakeholders.

Fig. 19 shows the scoring scheme which has been developed for the water heater.

The water heater component ranking is produced using the scoring scheme in fig. 19 and the categorised component actions shown in fig. 18. As a result of feedback from water heater users, a 5:1 weighting is applied to reflect the relative importance of the “output” condition compared with the “no output” condition. The scores for the two operating states are added as shown in fig. 20 for a process modelled equivalent to the “device” based component ranking in fig. 15. Note the contrasting priorities derived from the two methods.

Fig. 20. Process-based water heater component rankings

3.6. Step 5: Value Optimisation Analysis

The goal of Value Analysis is to find and improve areas of a product which are poor value, while maintaining or enhancing areas which provide good value. By comparing functional worth against cost, high value and low value components can be clearly identified. Once we know the low value components, we can focus on finding solutions which address the root causes of poor value. Poor value components will most likely become candidates for trimming. In the previous sections, we have applied two different modelling approaches (“device” focused and “process” focused) to assess the relative worth of the various parts of the water system.
3.6.1. Cost and worth comparison – “device” modelled

In conventional Value Analysis all component costs are allocated against product functions – a process which can be both subjective and open to challenge. As mentioned previously, in the TRIZ-based Value Analysis method the continued focus on product hardware greatly simplifies cost allocation. This means that the comparison of worth and cost is shown for product components and not functions. There are a number of ways to visualise component worth and cost. A traditional method in Value Analysis uses a bar graph to show functional worth and cost for each function. In TRIZ-based Value Analysis, a similar diagram can be produced using system components in place of functions. Fig. 21 shows a graph comparing component worth and cost for the water heater derived from the “device” modelling approach. This graph lists the components in descending worth with costs for each. Both the worth and cost data have been shown as percentages to make it easier to visualise areas of good and poor value.

Fig. 21. Graph comparing cost and worth for water heater components based on “device” modelling method.

In Value Analysis, the first candidates for value optimisation are usually those with higher costs in the least important areas. In the case of the “device” modelled analysis, two components can be identified immediately from the cost versus worth graph:
- The thermostat
- Packaging & test

In order to get a clearer view of good and poor value, we can calculate the value ratio. The value ratio is a relative measure of value and is derived by dividing the percentage worth by the percentage cost for each component. Fig. 22 shows the value ratio graph for the water heater parts. The dotted line shows the average value ratio calculated. Any component below the line has less than average value.

Fig. 22. Graph of value ratio for water heater components based on “device” modelling method.

The “device” model derived value ratio graph reveals other potential value optimisation opportunities. In priority order, the outer casings, neon light, hot tank, PU foam and heating element are all water heater components with lower than average value.

3.6.2. Cost and worth comparison – “process” modelled

When the results from the “process” modelling approach are used to generate a cost vs worth comparison, the profile of results is strikingly different. Fig. 23 shows a graph comparing the “process” model derived component worth and cost data for the water heater.

Fig. 23. Graph comparing cost and worth for water heater components based on “process” modelling method.

Reviewing this graph initially highlights the same two poor value components as the “device” analysis – packaging & test and the thermostat. However, the lower worth of the hot tank means this component may also present an opportunity. To get a clearer picture of water system component value, the value ratio is once again calculated and graphed. Fig. 24 shows the value ratio for the “process” modelled water system components.

Fig. 24. Graph comparing cost and worth for water heater components based on “process” modelling method.

Reviewing this graph initially highlights the same two poor value components as the “device” analysis – packaging & test and the thermostat. However, the lower worth of the hot tank means this component may also present an opportunity. To get a clearer picture of water system component value, the value ratio is once again calculated and graphed. Fig. 24 shows the value ratio for the “process” modelled water system components.
When the value ratio graph is reviewed it becomes even clearer that the results from the “device” and “process” modelling approaches differ greatly. Now the hot tank can be seen as providing particularly poor value – even worse than that of the thermostat, while the heating element is shown to provide above average value.

3.6.3. Cause-effect analysis

In TRIZ-based Value Analysis, the poorest value system components are prioritised to be trimmed first. The cost and worth comparisons from the “device” and “process” models highlighted the thermostat and product packaging as priority opportunity areas but only the “process” derived outputs highlighted the hot tank as a key priority. One important question still needs to be resolved before the hot tank can be trimmed - why is the hot tank so expensive? This question can be answered by performing a cause-effect analysis.

The starting point in cause-effect analysis is the initial problem. By asking “Why?” or “What is the cause of this?” deeper reasons for the problem are uncovered. If two or more causes all have to be present for the initial problem to occur, the causes are connected to the problem with & (logical “AND”). If the presence of either one of the causes is enough to lead to the problem this is connected to the initial problem with an OR. At the end of the analysis, five root causes of to the problem of “hot tank is expensive” are identified – see fig 25.

- Root cause 1: Material and processes to make hot tank are expensive – solution direction 1: replace the current materials and manufacturing process with a lower cost alternative.
- Root cause 2: water temperature increase is high – solution direction 2: reduce the level of temperature increase required
- Root cause 3: hot water demand rate is high – solution direction 3: reduce the required hot water delivery rate
- Root cause 4: limited amount of energy available to heat water – solution direction 4: increase the amount of energy available to heat the water
- Root cause 5: water has a certain specific heat capacity – solution direction 5: change the properties of the water

As each root cause is logically connected to the initial problem by an AND, a strong solution to any one of the five root causes will resolve the problem “hot tank is expensive”, especially if it enables the hot tank to be trimmed completely. In a later section, we will discuss various options which follow these solution directions.

3.6.4. Ideal system analysis

In addition to the normal cost-focused perspective of value, the TRIZ concept of value can help during this stage of Value Analysis to increase the scope of the options open for value optimisation. Value can be defined in TRIZ terms as the sum of the useful functions divided by the sum of all harmful functions and costs.

In the TRIZ concept of an ideal system, a product can be said to have infinite value if either its level of useful functionality becomes infinite or the level of resource required and any harmful factors associated with the product’s operation become zero. This means that an ideal product’s functions are delivered in zero time, using zero energy, zero substance and zero information content. The resource usage profile of any product can be studied to determine how far away it might be from an ideal system. Fig. 26 shows a time-based resource usage profile for the water system in typical operation.
Analysing resource usage in the water from the perspective of substance, energy, information and time leads to the following conclusions and solution directions for each category:

**Substance:** The substance of the target is required by the end user and in the case of the water heater is found to be sufficient. However, from an ideal system standpoint, the substance of the water heater itself is only needed when the function “provide hot water” is needed – i.e. when the system is providing an output. This thought leads to solution direction 6: the water heater system should only have substance when it is delivering an output.

**Energy:** The level of energy flow at the start of system operation (i.e. when the heater is switched on from cold) is excessive. The laws of physics require a certain amount of energy to be used to re-heat the water following operation, however, there are limitations in the way the water heating element configuration converts electrical energy into heat energy and transfers that energy into the water. Solution direction 7: Increase efficiency of water heating by shortening the energy flow path.

**Information:** The water heater indicates its energy usage to the user. The level of information provided may be excessive. Solution direction 8: remove the need to communicate information about system status.

**Time:** In order to dispense hot water, the water heater needs to provide output for a certain amount of time as defined by the end customer. Ideally, any other resource use outside of this time (which is not required to satisfy the laws of physics) should be eliminated. When findings from the time and substance usage profile analysis are combined, it is clear that the current water heater format is far from ideal and should be improved – see solution direction 6.

### 3.6.5. Value Improvement

In the previous section it became clear that the current water heater design requires the hot tank to store a large amount of thermal energy in the form of heated water. The thermal store is needed so that the water heater can deliver a certain level of hot water delivery performance. This in turn is driven by other system limitations governed (to an extent) by the physics of water heating. A number of solution directions were identified using these insights and the ideal system analysis. In this section each of these solution directions will be explored in turn.

#### 3.6.5.1. Value Improvement from the cause-effect analysis

The cause-effect analysis highlighted five solution directions which will now be used to help identify potential value improvement concepts.

**Solution direction 1:** replace the current materials and manufacturing process with a lower cost alternative. One way to reduce the cost of a water tank in a high volume manufactured water heater is to replace the current complex welded and fabricated assembly with a simpler plastic injection moulded thermoplastic unit.

Rather than reducing the hot tank cost, the remaining solution directions in this section are aimed at partially or completely trimming the hot tank from the system, while still maintaining its function – see fig. 27.

![Fig. 27. How to trim the hot tank?](image)

**Solution direction 2:** reduce the level of temperature increase required. Assuming the output water temperature has to stay at its present value, the only remaining option is to increase the incoming water temperature. A review of a typical home reveals a number of potential resources which can be used to increase water temperature. Waste heat is often available from air conditioning, heating and cooking systems. Additionally, most houses already have a supply of hot water which can be boosted to the required temperature by the water heater, greatly reducing the energy storage requirement.

**Solution direction 3:** reduce the required hot water delivery rate. Any change to water delivery rate requires a good understanding of how the hot water output will be used. In this application, only limited changes to the water delivery rate are possible.

**Solution direction 4:** increase the amount of energy available to heat the water. There are a number of possible ways to increase the amount of energy available for water heating. In most houses in the UK there is a mains electricity supply with a higher rated current – commonly used for electric cookers which can be used to power the water heater. This form of tank-less electric water heater is already commercially available – see fig. 28.

![Fig. 28. Tank-less electric water heater](image)

Alternatively, the water can be heated using the domestic gas supply. This functionality can even be merged with the central heating boiler in the so-called combination boiler, completely eliminating the need for a separate water heater.
Solution direction 5: change the properties of the water.
At first sight, it may seem impossible to change the properties of water. However, it has been shown that the thermal capacity of water can be lowered significantly by adding certain compounds – e.g. salt. A paper written by Fritz Zwicky in 1926 [9] explains the physics behind this effect. Salinated water supplies are often used in areas where there is a risk of limescale build-up.

3.6.5.2. Value improvement from the ideal system analysis

The ideal system analysis generated a further three solution directions which we can now review.

Solution direction 6: the water heater system should only have substance when it is delivering an output. To achieve this, we should check if any existing resources can provide the water heater functions. Interesting resources include: the existing hot water supply, pipes and hot tap and the water itself. The thought of the water heating itself leads to the concept of direct ohmic or Joule water heating. Not only does this solution remove the need for a heating element but it also leads to enhanced water heating efficiency, addressing solution direction 7: Increase efficiency of water heating by shortening the energy flow path.

Solution direction 8: Remove the need to communicate information about system status. When we review the function of the neon we find it is only needed because the large volume of water in the hot tank takes so long to heat up. Trimming both the hot tank and its thermal mass means that hot water is available instantly, eliminating any need to communicate information.

Fig. 29 shows the hot water delivery concept resulting from the previous analysis. Ohmic heating has been combined with the existing resources of the domestic hot water supply.

4. Conclusion

When a product effects changes on its “target” as in the case of the water heater, TRIZ-based Value Analysis using product-process modelling provides a far more reliable indication of poor value areas of a design than traditional TRIZ “device” modelling. In addition, applying a process perspective to a system’s operation greatly facilitates use of other powerful tools such as ideal system analysis. The methods outlined in this paper have been successfully applied in real-life Value Analysis projects. It is also interesting to note that the scope of the product-process modelling approach may be broader still. We would postulate that any technical system can be modelled as a process to modify or maintain the condition of a “target”. We would further suggest that modelling a system in this way can yield important insights which may not be exposed by other forms of analysis.

References

BIG Patent DATA and PanSensic Social Media Contradiction-Mapping Analysis: an opportunity for TRIZ

Simon Dewulf\textsuperscript{a}, Darrell Mann\textsuperscript{b}

\textsuperscript{a} AULIVE Pvt Limited, CEO, Byron Bay, Australia
\textsuperscript{b} Systematic Innovation Network, CEO, Devon, United Kingdom

* Corresponding authors E-mail address: s@aulive.com and darrell.mann@systematic-innovation.com

Abstract

Today the world says BIG DATA, TRIZ can say BIG Patent DATA. And unlike BIG DATA, BIG Patent DATA has structure. Most patents have a title and abstract (summary), claims (proposed solution), description (problem), citations (relation), and text structure. Couple this with the step-change advance in the ability to analyse social media content being realised by the PanSensic contradiction and frustration finder tools, and, the paper hypothesises, the ability of innovators to capture and solve the ‘real’ problems within a domain looks set to be transformed.

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1. Introduction

One of the biggest unsolved contradictions of TRIZ is that between the simultaneous need for both ease of use and efficacy of result. As time passes, the extent of the contradiction appears only to grow: fewer and fewer people have the time to go and learn all of the various foibles of the full methodology, while at the same time, the complexity and inter-connectedness of problems becomes greater and greater. Put simply, there are no simple problems any more, and no-one has any time to learn how to solve the difficult ones. The TRIZ trends, of course, provide significant clues about how the contradiction will ultimately be solved. The biggest clue comes from the increasing-decreasing complexity trend, a version of which is illustrated in Figure 1:

![Increasing-Decreasing Complexity Curve And TRIZ](image)

**Fig. 1. The Increasing-Decreasing Complexity Curve And TRIZ**

This paper examines two aspects of the contradiction, both helping users to get beyond the peak of the complexity curve and to a step-change increase in capability. The first of the two aspects examines the emerging ‘science of reading between the lines’ contained in the TRIZ-derived ‘PanSensic’ suite of problem finding measurement tools. The second examines how the PatentInspiration software is helping problem solvers to far more quickly find the ‘someone, somewhere, that already solved their problem. Following two brief sections describing the two suites of tools, the bulk of the paper is devoted to a pair of case study examples in which we aim to demonstrate how the two toolkits work together to offer users a ‘one plus one is greater than two’ increase in problem finding and problem solving capability.

2. PanSensics

‘What gets measured gets done’, to paraphrase famous measurement author, John Lingle, is an oft-used business mantra. Introducing a new measurement or measurement method is one of the most effective behaviour change strategies within any organisation. The problem is that most measurements are based on what leaders assume is possible, rather than what is necessarily right. The seeds of most
change and innovation attempt failures can be shown to have been sown the moment that someone made the decision to listen to information that was merely easy or convenient to acquire. 95% of marketing surveys fall into this category: we know we’re supposed to go and ask the customer; we just don’t know what we should really go and ask them. Or how we should ask them. Or how to listen to what they’re not trying to tell us.

The same phenomenon applies equally well to what goes on within an organisation: over 75% of all change programmes instigated within enterprises will fail to deliver a net benefit. Why? Because managers use measurements that were easy to make in order to steer the change, rather than the things that will actually help drive the business in the chosen direction. Not to mention the related problem that people don’t always tell the truth, whole truth and nothing but the truth. Few employees are likely to reveal things they fear may jeopardize their status or job.

In essence, then, there are two sides to the measurement challenge that have come to confound managers and leaders: the first is knowing what to measure, the second is knowing whether what we’ve measured has been measured accurately.

PanSensics is the emerging science of objectively and accurately measuring the un-measurable: how much do your customers really trust you? how cool do they think you are? how big is your reserve of goodwill? how engaged are your employees? how proud of the organisation are they? How much mutual respect do different parts of the business carry? It’s also about measuring realities rather than what people think are the things we want to hear. It is also the outcome of a 10 year programme of research taking in several hundred thousand case study datapoints.

3. Measuring The Right Things

If we examine the sorts of things that managers typically measure inside and across organisations, a distinct hierarchy rapidly emerges (Figure 2). The large majority of measurements are made based on things that are visible. Not surprisingly, when we can physically see something it becomes easy to measure. It is very easy, for example, to measure the number of products that were shipped during the previous quarter. It is similarly easy to see how many customers came through the door, how much money they gave us, how many people turned up for work, how many components they manufactured or assembled, or how many patent applications they generated. All of this kind of stuff is really easy to build into spreadsheets and ERP systems. And so we do. To the extent that most businesses are managed based almost entirely on what Excel or SAP is telling us.

At the next level up the importance hierarchy come ‘interactions’. Measuring things is one thing, measuring the relationships between those things is more difficult, largely because their level of visibility is an order of magnitude less. If the Excel spreadsheet is the de facto standard for measuring physical entities, the equivalent for the measurement of interactions are the Gantt chart, KPIs and ‘balanced scorecard’.

These are the management devices that informs the team how much progress has been made; whether the review meeting happened; whether the action was completed; was the final report received; were the year’s objectives met. Generally speaking, provided an interaction can be described on a Gantt chart or in someone’s KPI catalogue, managers are generally happy that the things under their responsibility are ‘under control’.

While the construction and maintenance of Gantt charts and KPIs might represent a lot of hard work, and hence tend to convey the impression that we have done the best we can hope for as managers, the information they provide often has little correlation with the next level in the measurement hierarchy: outcome. It is very easy to colour the bar chart to say we held the consumer panel and then fill in the milestone triangle when we publish the analysis report. It is much more difficult to measure whether the forum or the report it produced delivered any kind of useful outcome.

The first big problem here is that, by definition, the outcomes are end-to-end results that only occur after the fact. We might only know, for example, that a consumer is happy with our new product launch a year or more after the first products were shipped. In this external-facing world, the time it takes for the measurement to ‘close the loop’ and provide the feedback that we’re doing the right things is usually way too long to have any impact on what we do. The second big problem is that, because outcomes are even less visible than interactions, it is difficult to begin to know how to construct a sensible way of making a measurement at all. Take an internal outcome like engagement: how engaged are your employees? A question that, having expressed it, almost any manager would be negligent if they said they wouldn’t like to know.

Never mind the fact that there is a still more difficult level to the measurement hierarchy beyond outcome: meaning. Meaning is what ultimately comes to drive all of our actions and behaviours in life: both as customers and employees – what meaning do I derive from the products and services I purchase? What meaning does my work bring to my life? Not only is ‘meaning’ less visible than even outcomes are, but the time lag between something I buy or do and the meaning I am
able to extract from it can sometimes be extraordinarily long. Bob Dylan, a notably reluctant interviewee, is frequently asked what his lyrics ‘mean’. The answer has often been a shrug of the shoulders and a curt, ‘ask me in twenty years’.

Meanwhile, the 800lb gorilla in the room in both the outcome and meaning domains, is whether the result was an accurate one in the first place. Did your employees complete that engagement questionnaire with the aim of telling you the truth? Or the sort of truth they thought you wanted to hear? Or the truth that is mostly likely to secure their annual bonus?

4. Measuring Things Right

When someone asks you what the last quarter’s sales were, or whether the design review took place, it is very easy to respond with the truth. We simply have to go look thing up in the CRM system or look at the latest version of the project Gantt charts. We might know that either or both of these questions might carry a host of awkward additional pieces of knowledge – like how many unhappy customers we didn’t serve, or that the review was a complete waste of everyone’s time and effort – but, thankfully, those things weren’t what we were asked. Measurement systems that measure the easy physical and interaction stuff very quickly tend to become excellent blame deflection mechanisms. If ‘what gets measured gets done’ is a key management aphorism, ‘what gets measured, quickly gets corrupted’ isn’t too far behind. When a manager tells a team member, ‘don’t let me catch you doing that again’, it almost guarantees that the team will indeed not be caught again. It also, in most organisations, guarantees that whatever it was that was being done is still going on, but now in such a way that the management team will, per instruction, never find out that it is being done.

When it comes to measuring the important outcome and meaning stuff, we get right to the heart of what makes us human. And unless there is a high level of trust, we’re very unlikely to share with others what we’re actually thinking. Most organisations understand the importance of soliciting inputs from people in the form of stories and so soliciting inputs from people in the form of stories is an excellent way of capturing what they’re actually thinking rather than what they think you want to hear.

Beyond these theoretical foundations, the rest of the PanSensic capability derives from the technologies that come with the emerging ‘Big Data’ world born of the Internet and social media mass-communication phenomena and, increasingly, Cloud computing. Being able to ‘scrape’ enormous quantities of social media content is already coming to drive a lot of marketing activity. Alas, in true garbage-in-garbage-out fashion, if you don’t know how to scrape the data meaningfully, it simply remains as data. All noise and no signal. Signal – the only useful stuff – is about being able to
read between the lines. PanSensics, in this sense, is quite literally the science of reading between lines in order to capture meaning.

5. PanSensics: Measuring Customer Frustration

When it comes to understanding which problems are more important than others for an innovation team to go solve, evidence from the FMCG sector clearly highlights the presence or otherwise of consumer frustration as a key indicator. Frustration is the mother of innovation. One of the first PanSensic tools to be built was one capable of analysing large quantities of narrative data – from consumer panel verbatims, social media content, Twitter feeds, blog sites, etc – and extracting emotion-related content. The current version of the tool extracts meaningful data and first categorises it into a number of positive and negative emotions using first a keyword search and then a semantic context check. Having identified the various different emotions, each category can then be interrogated in more detail. In the case of frustration emotions, the next job of the software is to identify precisely what it is that customers are expressing frustration about. When this classification is performed, in line with the JP Morgan quote, the software is designed to divide assess the level of frustration along tangible and intangible axes. Then, within both, it establishes whether frustration with a given attribute or property of, say, a product is due to needs being over- or under-served.

Figure 4 illustrates a typical Frustration Map. The data underpinning this analysis comes from a social media scrape of consumer views about non-alcoholic beverages. The circle at the centre of the Map is intended to indicate properties where tangible and intangible needs are satisfactorily met. The further a property is plotted away from this central region, the greater the level of frustration customers are experiencing. In the Figure 2 plot, the greatest frustrations being expressed are thus sweetness, calories, aftertaste and lack of choice.

6. PanSensics: Measuring Customer Contradictions

Building on the central nature of Contradiction in the TRIZ philosophy, building a PanSensic tool to automatically uncover customer conflicts and contradictions was high on the priority list. The first version of the resulting ‘Contradiction Finder’ is reported here for the first time.

Developing the Contradiction Finder tool required a two-stage search approach when scraping narrative input data. In the first instance is a need to identify keywords signifying the presence of a conflict or contradiction. This database of keywords includes contradiction signifier words and phrases like ‘but’, ‘however, ‘unfortunately’, ‘chicken and egg’. Having identified the presence of such phrases, the semantic part of the PanSensic engine then looks upstream and downstream of the contradiction signifiers to identify words and phrases representing the two sides of the conflict pair. Perhaps not surprisingly, the ontology adopted to categorise the contradictions uncovered is the one used in the latest 50-parameter version of the Contradiction Matrix – Figure 5.

Figure 5: PanSensic Contradiction Finder

By way of example, Figure 6 highlights how a piece of narrative text containing a contradiction is mapped onto the Contradiction Matrix:

Figure 6: Contradiction Finder Algorithm Exemplar

For our two case studies, the narrative scrape revealed the following high priority contradictions:

CASE 1: Beverage
Sweet taste without calories (‘negative calories’?)
- no bad aftertaste
- More concentrated sweet taste to reduce amount required
- Sweet taste that produces feeling of satiety (i.e. we full like we're 'full')
- increasing desire for 'natural' and away from 'artificial'
- ‘natural’ but also long shelf-life
- natural and ‘pleasant odour’ (also, can odour help trick the brain into thinking we’re ‘full’)
- olfactory cues that last a longer time (human sense of smell is very poor; we quickly become accustomed to a scent and forget it is there)
E.g. stevia is often cited as a sugar-substitute, but most customers would say that it leaves a bad aftertaste, so is there something that could prevent or mitigate this secondary problem?)

CASE 2 Trans-dermal Medication Transfer:
Needles/Catheters (medical devices that transfer fluids through or across human skin layer)
- biocompatibility (long term needle/catheter users suffer continual infections) - biggest frustration.
- friction/resistance to insertion (also related to biofilms - can we have a surface that biofilms can’t form on?)
- want smallest area, but want to be able to transfer high quantities of fluid
- disposable versus re-usable
Having used PanSensic to find some good problems to solve, we now switch our attention to how PatentInspiration can assist problem solvers in generating meaningful and actionable solutions:

7. Identifying solutions in and outside the domain:
For this research PatentInspiration was used. It is a database of all patents, with some TRIZ-like analysis and visualization tools on top.

Within PatentInspiration, a combination analysis allows to select a set of e.g. 5 keywords, after which all patents are examined containing all 5, different combinations of 4,3,2,1 of the keywords in one schematic. We configured a combination analysis in all patents of the underlined keywords above in the figure below:

![Figure 8: Combination Analysis of keywords](image)

The first patent (containing all search strings) claims a combination of different steviol glycosides, which is taught to achieve an extract that has low or no aftertaste. In total, there are about 37 patents addressing the aftertaste of stevia in their invention (title and abstract description).

Going out of the domain, abstracting ‘aftertaste’ in all products, we are hitting 1923 patents worldwide (mentioning ‘aftertaste’ in title or abstract). One of the ways to visualise the areas of aftertaste in this patent pool is to make a text pattern search on ‘nouns’ in 3 word proximity with ‘aftertaste’, giving the visualisation below. Different areas of aftertaste research include beans, beer, calcium, cream, wine, zinc and even cigarettes.

![Figure 9: Other areas (Nouns) in ‘aftertaste’ pool](image)

8. Generating conflict matrixes in the classification non-alcoholic beverages
A23L2/00 (this is a classification code of patents) gives you the classification of ‘non-alcoholic beverages,...’ in which 26305 patent documents are available. By looking at the modifier analysis, one can identify what is increased, decreased or stabilized in the patent pool. Generating an X-Y graph of X – increase versus Y-decrease, a conflict matrix is automatically generated.

![Figure 10: increase versus decrease modifiers](image)

Selecting “e.g. X-flavour versus Y-calorie” shows two P&G patents proposing to increase the flavour with edible acid or salt, without increasing the calories. Within “X-sweetness versus Y-bitterness”, 4 patents show how to increase the sweetness whilst suppressing the bitterness of sweeteners. Note that they describe the conflict in beverages but likewise in foodstuff, medicine and tobacco products. Of course, since this selection of parameters is automated, some might not be relevant to your quest.

Based on the PanSensic consumer data, you can preselect a custom list of parameters; for example sweetness, taste, flavour versus calories, aftertaste, bitterness, obesity.
Which creates a customised conflict matrix, now in the domain of non-alcoholic beverages, but you can do the same for all patents.


To start off with a more abstract title, the classification (IPC and CPC) brings 45801 patents on “Devices for bringing media into the body in a subcutaneous”, with subclasses including catheters.

As discussed in previous papers7,8,9 we can assume that many of the principles or trend steps are identical to a property change, and that most properties are expressed in adjectives. By requesting a map of adjectives of the noun needle or syringe we generate a following wordcloud:

We can identify a TRIZ like adjective “hollow”. By varying that property, let’s search for porous needles in our patent pool. What would be the benefit of a porous or microporous needle?

The benefits claimed are multiple. The needle has minimum intrusion (in the second picture, even just a stretch rather than hole as it is tipped as opposed to circled) however the dispersion is better.

Although the inserting area is small, the delivery area (side holes) is much larger, giving a high flow rate, as required in the briefing, the conflict breaker smaller insertion, high flow rate, porosity in another dimension. This was just one property looked at, for a 360 innovation round, one can generate an evolutionary potential radar diagram of ‘needle’.

10. Value equation: what is performance, harm, interface or cost?

If we generate a value equation on our patent pool, we come across some of the briefing elements. The software is examining the patents in a TRIZ-like way, distilling in specific locations of the patent texts, the wording in context that is related to either performance, harm, interface or cost, and generates the graph below.

In the harm section, we can read needle-free, which gives us 533 patents on needle-free injection systems worth exploring. Needle free can be related to two other term groups distilled in the value equation, in the interface section autoinjector(288), with auto-injector(424), autoinjectors(190) and auto-jectors (313), and the set called self-injection (258) In the Interface section, we read self-destroying (231), self-destructing (290) and self-destruction (778) bringing material to one-time use needles or syringes.

Finally, you can find all the self-solutions of the topic in the self analysis.

11. Ideal needle is no needle

Although not extensive, and built in a random fashion, Moreinspiration.com collects recent innovations across domains. By searching “needle-free” two innovations appear. The first one is a needle-free blood test patented as “Handheld Device for Drawing, Collecting, and Analyzing Bodily Fluid”
Needle free injectors are a class on their own. They are used in areas a slightly larger than transdermal. A separate search brings 2211 patents on needle-free systems across all domains (compared to 1722 in domain). The extra domains and classifications include dental, food, nozzles, machinery, jet propulsion etc.

12. Modifiers: What is being increased, decreased or stabilised?
Bringing the modifiers back to our briefing, we can identify decrease “cross infection (135)” and decrease “infection (80)” as in the value equation before on the harm, we can find harm: infection (80), giving us all patents working on the prevention of infection in our selected patent pool. These are pre-classified in active word sentences, the word ‘infection’ in the pool is detected in 1011 patents.

![Figure 17: Modifiers of our patent pool on medical devices](image)

13. Shopping list
An easy way to make a shopping list of all terms, one can generate a word cloud of all the desired or undesired properties or functions, within the filtered results.

![Figure 16: consumer wants hit list of patent pool](image)

Each term can be used for an out of domain search, a shopping list. The total can be overlayed versus time, or companies, as shown below. Who is working on what?

14. Conclusions
The problem finding tools in patents are present, though not consumer prioritised, as we saw on aftertaste. The tools are therefore indicative, from an IP standpoint, and what researchers are mostly working on. However that is no guarantee, it is aligned with the consumer want. That is where Pansensic tools can bring in their value[12]. The problem finding approach can therefore best be effectuated with a combination of both consumer and patent data.

Once the problems are well-defined, the patent database will be ideal to identify the outside area’s to look at. Moreover, large companies with thousands of patents can use the tool for internal open innovation, i.e. who in my company could help me solve this problem, be it from another domain.

This phase of identifying across domain solutions is thereby best done by a well operated computer analysis. It is up to the person to select, navigate, filter, explore, decide and finally select a technology import.

BIG Patent DATA has a tremendous advantage over BIG DATA, that the quality is much higher, but above all it is structured, allowing us to know where the solution is described, where the problem is stated, who is referring to it etc., making the potential for BIG patent DATA much larger for future problem solving, innovation and technical marketing tools.

Combining the TRIZ-related research, the notion of property-function relations in adjective-verb pairs(2), with patent research algorithms will greatly reinforce the functional use of existing research, boost technology transfer, and bring us a step closer to future artificial creativity. After all TRIZ was distilled in a similar fashion, only manually.

References
[12] www.pansensic.com

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On the identification of contradictions using Cause Effect Chain Analysis
Christoph Dobrusskin
Philips Innovation Services, High Tech Campus 7, 5656AE Eindhoven, The Netherlands
E-mail address: c.dobrusskin@philips.com

Abstract
Modern TRIZ has evolved from a methodology used to solve technical problems to a method that increasingly incorporates tools to analyze initial problem situations before deciding on core problems formulating contradictions and problem solving. One of the tools used for this purpose and assimilated into TRIZ is the Root Cause Analysis (RCA) [1] in its various forms and derivatives: Fishbone or Ishikawa Diagram [2], Cause Effect Chain Analysis and Root Conflict Analysis [3] (RCA+). From a practitioner’s viewpoint it is not always easy how to link these analytical tools to TRIZ problem solving tools, and particularly to the formulation of contradictions. The present paper investigates this issue, and gives some advice on how the results of the analytical tools can be directly used as input for the problem solving tools.

Keywords: TRIZ, Cause Effect Chain Analysis, CECA, Root Cause Analysis, RCA, Fishbone Diagram, Ishikawa Diagram, Root Conflict Analysis, RCA+, Contradictions

1. Introduction
The analysis of initial problem situations is one of the key elements that allow the powerful TRIZ problem solving tools to be used to their full extent. Indeed, the saying goes that many TRIZ professionals don’t solve the problems that they are initially presented with. TRIZ practitioners use a wide range of analysis tools for a variety of different purposes: from ideality via S-curve analysis and the analysis of technology trends to Function Modeling (FM) and Cause Effect Chain Analysis [4].

The Cause Effect Chain Analysis has proved to be one of the more popular tools for a number of reasons: its principles are easy to learn and use, it is extremely flexible in that it can be applied to a variety of problems of differing nature, it can drill deep – to the size of atoms if necessary - where other tools often stop, and its results are easy to communicate.

However, it seems not always easy to translate the findings of the Cause Effect Chain Analysis into problem formulations – contradictions – that can be directly used and integrated with the TRIZ problem solving tools. Root Conflict Analysis is a commendable exception and will be discussed as well.

It is the purpose of this paper to elucidate how the Cause Effect Chain Analysis can be used and tweaked to directly lead the user to the formulation of contradictions.

2. Cause Effect Chain Analysis and its variants
The general purpose of Cause Effect Chain Analysis and similar tools is to investigate the underlying causes and their interdependencies for an observed effect and to visualize the result in a graphic way. In most cases this is a negative effect, some disadvantage or problem that the project tries to overcome.

2.1. Fishbone diagrams
Root cause analysis is used to investigate the underlying causes of a specific event and is often applied to quality issues in manufacturing and industry. A well-known graphic representation is the Fishbone or Ishikawa Diagram [2].
Related causes (or ideas for causes) for a specific problem are grouped together into categories and are organized into a diagram that resembles the skeleton of a fish, hence the name fishbone diagram. Typically those categories include items such as Machines, Material, Methods, People and so on (Fig. 1).

Fig. 1. A typical Fishbone Diagram investigating a problem with a drilling machine.

The Fishbone Diagram is an excellent way to represent an easy and standardized way of investigating the underlying causes, be they of a technical or other nature. However, the result does not lend itself to be seamlessly integrated in a typical TRIZ project. In particular there is no intuitive way to re-formulate any of the found underlying causes into contradictions which can then be solved with TRIZ tools.

2.2. Cause Effect Chain Analysis

Another simple but effective tool for root cause analysis is the Cause Effect Chain Analysis. In a Cause Effect Chain Analysis, the Problem to be solved is taken as the starting point and written into a box [5]. It is next asked: “what causes that problem”? Possible answers are written down into new boxes inserted below the original one, and those new boxes are connected with the original problem box by arrows. If there are more than one cause underlying the problem, those are connected by an AND statement if they both need to be present to cause the problem, and by an OR statement if they independently lead to the problem. Figure 2 shows the Cause Effect Chain Analysis for the unreliable drilling machine. In the context of TRIZ projects Cause Effect Chain Analysis are mostly done focusing on the technical causes. To avoid ambiguity, care has to be taken to describe the contents of each cause – each box – carefully and clearly.

In its basic form the Cause Effect Chain Analysis is an effective and easy to use tool to explore specific problems or to investigate products for general improvement. It is easy to communicate; people who have never used it can intuitively understand and add to it. However just like the fishbone diagram it does not lend itself easily to the formulation of contradictions.

2.3. Root Conflict Analysis

The Root Conflict Analysis was developed by V. Souchkov [3] to investigate the root cause(s) of a problem in the same way as the Cause Effect Chain Analysis, but taking a way to formulate contradictions into account. It uses a graphic format that illustrates contradictions directly. Apart from minor differences in the graphic representation it is identical to the Cause Effect Chain Analysis. For example negative effects are denoted with a minus sign, positive effects with a plus sign, contradictions with a plus and minus sign etc.. For each cause one asks the question if this cause is present because of any positive effect that it produces. If present, these effects are added into the graphic representation, by adding a box containing the positive effect above the box containing the cause, and connecting it with an arrow (Fig. 3).

Fig. 2. A typical Cause Effect Chain Analysis for investigating an unreliable drilling machine (incomplete overview).

Fig. 3. A Root Conflict Analysis is shown

Causes which have both, a positive and a negative effect form the basis for formulating a contradiction. In the example the gears of the transmission are very thin, which has the positive effect that the gears – and the drilling machine is of light weight, but has the negative effect that the gears break easily (Fig. 4).
This way of identifying contradictions directly through the analysis has a number of advantages. Not only does it visualize the contradiction, but it is also linked directly to the formulation of the contradiction. Finally, if a cause can be formulated as a contradiction, the cause is not further explored. This establishes a guideline when to stop further exploring a cause effect chain.

3. Other ways of identifying contradictions in Cause Effect Chain Analysis

Two additional ways can be described to identify contradictions in Cause Effect Chain Analysis or Root Conflict Analysis.

The first kinds of contradictions tend to appear in using Cause Effect Chain Analysis for general improvement projects. There are instances when an underlying cause of a problem appears on one branch of the analysis with a certain value or direction and on another branch of the analysis with the opposite value or direction. At times these sources of contradictions are not immediately obvious, but once identified, a contradiction can be easily formulated (Fig. 5).

![Fig. 5. A contradiction identified by opposite values of a single component but from different branches of the Cause Effect Chain](image)

The second way of identifying contradictions in Cause Effect Chain Analysis requires a bit more attention during the analysis of the causes. As Kepner / Tregoe [6] pointed out, each cause of a problem has an IST state (the state as it is), which is the state that causes the problem. On the other hand the cause also has a SOLL state (the state as it should be), which is the state in which the problem does not occur. By describing as precisely as possible for each cause the IST and SOLL state in the Cause Effect Chain Analysis or the Root Conflict Analysis, we can construct a Cause Effect Chain Analysis which is more precise and has more depth than would be possible otherwise (Fig. 6).

![Fig. 6. A cause effect chain analysis describing the causes as IST / SOLL statements](image)

In the TRIZ literature several guidelines exist on the basic nature of contradictions and those can be applied here to help identifying IST / SOLL descriptions suitable for the formulation of contradictions. Savransky [7], for example, cites the work of C. J. Terninko et al, who showed that in terms of the harmful or desired effects, physical contradictions can be separated into three groups:

- A FUNCTION is necessary to achieve something useful and not performing that function is necessary to avoid harm or achieve something else useful.
- A CHARACTERISTIC or PARAMETER of a system must be of a first value to achieve something useful, and that parameter also needs to be of a second different value to avoid harm or achieve something else useful.
- A PART OF A SYSTEM needs to be present to achieve something useful, and that part of the system needs to be absent to avoid harm or achieve something else useful.

Overall the exact description of the causes achieves a number of different objectives. Firstly, the causes are defined exactly, as in many circumstances parameters can be given that describe the two states. Fuzzy causes can be translated into measurable parameters - step by step. As a result the formulation of contradictions becomes easier throughout all levels of the Cause Effect Chain Analysis. At times, solutions that are not easily discernible through a normal Cause Effect Chain Analysis become readily apparent – even without the use of the TRIZ contradiction tools. Furthermore, the consequent addition of parameters helps to further elaborate the tree structure, as higher level parameters can be broken up into their respective components and the true root causes are easier identified (Fig. 7).
Fig. 7. A cause described with a higher level parameter is broken down into underlying causes.

By applying this way of working conscientiously, the Cause Effect Chain is, to a large extent, taken out of the realm of brainstorming [8] and put in a structured, factual framework. It also leads to a deeper analysis, as often a clear way is shown on how to break up a composite cause into the constituent underlying causes.

Finally, formulating contradictions for TRIZ becomes easy as the conflicting elements are clearly described.

4. Conclusions

Cause Effect Chain Analysis has over the past years become increasingly more interesting to TRIZ practitioners. The development of Root Conflict Analysis has formed a first step in linking this type of analysis to TRIZ tools. Two additional ways, modeling contradictions from different branches of the Cause Effect Chain analysis, and modeling the causes in the form of IST / SOLL statements have been shown in this paper. This should help to widen the adaptation and use of the Cause Effect Chain Analysis in the TRIZ workflow.

Acknowledgements

Many colleagues at Philips and many others in the TRIZ community have, in the last few years, knowingly and unknowingly contributed to the thinking process behind this paper. Many thanks, in particular to R. Waldner, V. Souchkov, Dr. S. Ikovenko and Dr. R. Adunka.

References

Abstract

The emerging of product-service system design is the result of the process that the focus of sustainable design is driven from the product design to strategic design. To achieve the goal of meeting the needs of the customers and reducing pollution and the consumption of materials and energy, designers have a mind to reduce system’s dependence on material products but strengthen the focus on product stakeholder systems and other resources which can be used in the all system. Transition from the product innovation to strategic innovation has become a trend, so applying TRIZ method to strategic innovation becomes very necessary. As for the strategic innovation, not only the product innovation but also the innovation of the whole system, including all product stakeholder systems, should be considered. It is a way of innovation of the higher level and the process is more complicated. Based on IFR and Standard Solutions, this paper studies the innovation of multiple stakeholder systems fusion in the product-service system. Research process is divided into two steps: first, on the basis of the Ideality of product service system, a standard to determine the multi-stakeholders is put forward. Second, stakeholder system is analyzed. Based on the Su-Field model, find out the problems existing in the system fusion process. And then figure out a solution by choosing appropriate Standard Solutions. Finally, the feasibility of this method is verified by an example.

Keywords: TRIZ; Ideality; Su-Field; Standard Solutions; multiple stakeholder systems fusion

1. Introduction

The problems in terms of resources consumption and environment pollution become prominent increasingly, which arouse widespread attention in the world. Sustainability is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. With the rise of sustainable development, there have been increasing needs for the sustainable solution rather than a single product. As a solution, product-service system (PSS) has received great attention. As the attractive design solutions based on a mix of material and immaterial components, PSS must satisfy the requirements of each of the stakeholders. It is an effective form of realizing sustainable products functions that build product-service system. It is necessary to coordinate the relationship between the interests of all parties and optimize the whole system resources to meet the requirement of sustainable development in the process of building product-service system. The design of multi-stakeholders fusion process belongs to the system design and the current research on this question is seldom. Gupta, S use Multi-Objective Genetic Algorithm to optimize the needs of various stakeholders. They take a case and explain the application of this novel methodology for a car manufacturing scenario. Idealized thought in TRIZ theory plays a crucial role in solving problems, which can be used as the target and basis of the multi-stakeholders fusion evolution route. Su-Field model, as a method of system analysis, can describe the system problems correctly by establishing the system structural model. It also can express the function of the technical system (subsystem) clearly by describing the system’s components and the correlation of the elements correctly using sign language. So Su-Field model can be used as effective tool for the multi-stakeholders fusion model research. Complex product design and manufacturing need the cooperation not
2. Concepts and tools illustration

I will introduce the concepts and tools that will appear in this literature in the following part.

2.1. Multi-stakeholders in three dimensions

The study of stakeholders comes from the study of product-service system and extends the study in this area further. So the aim of the study is also to provide costumers sustainable solutions that can meet customer needs. So we put forward a principle that stakeholders’ function connected must meet the customer needs and must keep the sustainable principles in the implement process. From the point of view of sustainability, stakeholders should be included in the whole life cycle but not only one stage such as production, usage, recycle and so on. From the point of view of meeting customer needs, producer should meet not only the core needs but also the service needs. So focus on the stakeholders except customer in the usage stage is necessary. Environment is the factors we should consider in the all process, so make it stakeholders in another dimension.

So multi-stakeholders are divided in three dimensions:

- Stakeholders in product life cycle (lateral stakeholders)
- Stakeholders in the usage process (lengthways stakeholders)
- Stakeholders in the environment (vertical stakeholders)

2.2. Su-Field model

Su-Field model is a general tool of system analysis. The smallest technical system consists of two kinds of substance and one kind of field, which can be extended if necessary. The Su-Field model analyze problem on the basis of representing the system to be designed by symbols showed in the Fig.1. There are some changes in using symbols in this literature which will be illustrated in the following content. The aims using Su-Field is to analyze the system functions and prepare for applying Standard Solutions.

2.3. 76 Standard Solutions

Standard Solutions is one of TRIZ tools for solving technical problems based on knowledge, which was finished by G.S.Altshuller and his associates between 1975 and 1985. It has 76 solutions grouped into 5 categories (Table.1). There is one tool closely related to the Standard Solution: Su-Field model. It will play better when combine Standard Solution and Su-Field model to solve problems.

### Table.1. Summary of the 76 Standard Solutions

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build or Destroy Su-Field</td>
<td>13</td>
</tr>
<tr>
<td>Increase Su-Field effectiveness</td>
<td>23</td>
</tr>
<tr>
<td>System transitions</td>
<td>6</td>
</tr>
<tr>
<td>Measure and Detect</td>
<td>17</td>
</tr>
<tr>
<td>How to apply Class 1 to 4 recommendations</td>
<td>17</td>
</tr>
</tbody>
</table>

The establishment of multi-stakeholders fusion model is divided into two steps: firstly, on the basis of increasing the Ideality of PPS, put forward a standard to determine the multi-stakeholders. Secondly, stakeholder system is analyzed, and based on the Su-Field model, find out the problems existing in the system fusion process. And then figure out a solution by choosing appropriate Standard Solutions.

3. The fusion of multi-stakeholders

Based on the formula of Ideality and the concept of product service system, the Ideality of PPS is defined as follows:

\[
\text{Ideality} = \frac{\sum UF}{\left( \sum \text{Expenses} + \sum \text{Harms} \right)}
\]

In this formula: \( \sum UF \)—the sum of useful functions. Expenses include the cost of raw materials, space occupied by the system, energy consumption, noise, and so on. Harms include waste and pollution. The four ways of raising the level of Ideality can be illustrated as follows:

1. Make the speed of numerator’s augment faster than the denominator’s;
2. Numerator increase and denominator decrease;
3. Numerator keep the same and denominator decrease;
4. Numerator increase and denominator keep the same.

In the way (1), denominator’s augment represent that the useful functions increase based on the cost of environment. It goes against the idea of sustainable design so that this way must be abandoned; in the way (2), useful functions increase and decrease the consumption of raw materials and energy and prevent pollution in all processes, which is the best way; in the way (3), useful functions keep the same but decrease the consumption and pollution; in the way (4), product more useful functions but do not influence the environment.

We can summarize the evolution route of PSS by the analysis in the above paragraph:

1. Increase the output of the useful functions

Transform the focus from product stage to use stage. Producer and other stakeholders should provide more technical service and support in use stage, which can help product extend service life and reduce use cost efficiently to improve customer satisfaction. Remanufacturer product refurbished products which consume fewer
Recycle
Use
F
F
F
(2)
(3)
stage and the consumption of resources and energy are the ineffective function. The pollution made in the production 'function isn’t satisfied completely which is the ineffective function. Product becomes the waste when it is used for a period of time, and energy consumption and pollution may come up in the usage stage, all of which is the harmful function.

The Su-Field model of stakeholder system in usage stage is expressed in the Fig.4. S₁ represents user, S₂ represents product, and F represents a complex model. In the usage stage, the effective function is that core function is implemented after the product is used, which satisfied core customer need. Because there is only user take part in this stage, the service needs aren’t satisfied completely which is the ineffective function. Because the recycle system isn’t complete, it is impossible that all used product are recycled. The loss of resources is ineffective function. The pollution formed in the disassembly process or the energy consumption in the material recycling process is the harmful function.

We can find that there are some problems in the all stakeholder systems in various stages which should be solved through fusion. The problem is within the scope of super system, depending on the application condition of Standard Solutions, so choose (3.1.1) standard solution-- system transfer (a): establish double-system or multi-system. Depending on the evolution route (2), we should track the material flow direction and enhance the utilization rate of the product. With this guidance, we solve the problem by connecting the lateral stakeholder in series. Organize the fusion results and we can get a Su-Field model of preliminary fusion in series (Fig.5). Dashed circle line represents that the integration formed between the stakeholders is insufficient function. The hollow arrows represent the phase transformation. In the Su-Field model of preliminary fusion in series, using the product in the usage stage help its core functions realized, which solve the ineffective function that core needs can’t be satisfied in the production stage. The system in series possesses the effective and complete function that core function is implemented. Recycling used product in the recycle stage efficiently prevent the waste appearing in the usage stage, but there will be the ineffective function that the resources will be lost owing to the insufficient integration formed between the stakeholders. Other functions in the individual stakeholder systems are not affected and maintained in the fusion system.

3.2. The Su-Field model of the fusion of multi- stakeholders

At first, analyse independent stakeholder system by Su-Field model. The Su-Field model of stakeholder system in production stage is expressed in the Fig.2. S₁ represents producer, S₂ represents raw material and character “F” represents a complex model. In the production stage, the effective and complete function is that producer manufacture product. Because the product isn’t used in this stage, core function isn’t implemented and core customer needs is the ineffective function. The pollution made in the production stage and the consumption of resources and energy are the harmful function.

The Su-Field model of stakeholder system in usage stage is expressed in the Fig.3. S₁ represents user, S₂ represents product, and F represents a complex model. In the usage stage, the useful function is that core function is implemented after the product is used, which satisfied core customer need. Because there is only user take part in this stage, the service needs aren’t satisfied completely which is the ineffective function. Product becomes the waste when it is used for a period of time, and energy consumption and pollution may come up in the usage stage, all of which is the harmful function.

The Su-Field model of stakeholder system in recycle stage is expressed in the Fig.4. S₁ represents recycler, S₂ represents used product, and F represents a complex model. In the recycle stage, recyclers recycle the used product and remanufacturers renovate the used product or turn the used product to the raw material, which is the effective and complete function. Because the recycle system isn’t complete, it is impossible that all used product are recycled. The loss of resources is ineffective function. The pollution formed in the disassembly process or the energy consumption in the material recycling process is the harmful function.

We can find that there are some problems in the all stakeholder systems in various stages which should be solved through fusion. The problem is within the scope of super system, depending on the application condition of Standard Solutions, so choose (3.1.1) standard solution-- system transfer (a): establish double-system or multi-system. Depending on the evolution route (2), we should track the material flow direction and enhance the utilization rate of the product. With this guidance, we solve the problem by connecting the lateral stakeholder in series. Organize the fusion results and we can get a Su-Field model of preliminary fusion in series (Fig.5). Dashed circle line represents that the integration formed between the stakeholders is insufficient function. The hollow arrows represent the phase transformation. In the Su-Field model of preliminary fusion in series, using the product in the usage stage help its core functions realized, which solve the ineffective function that core needs can’t be satisfied in the production stage. The system in series possesses the effective and complete function that core function is implemented. Recycling used product in the recycle stage efficiently prevent the waste appearing in the usage stage, but there will be the ineffective function that the resources will be lost owing to the insufficient integration formed between the stakeholders. Other functions in the individual stakeholder systems are not affected and maintained in the fusion system.
Depending on the evolution route (1), we should transform the focus from product stage to use stage. With this guidance, we solve the problem by connecting the lengthways stakeholder in parallel. Organize the fusion results and we can get a Su-Field model of preliminary fusion in series + in parallel (Fig.6). Unidirectional solid arrows represent directed function between stakeholders. In the Su-Field model of preliminary fusion in series + in parallel, adding the process, such as installation, maintain, repair, RMON and so on, in the usage stage, which provide users service support and implement the service functions. The ineffective function in last model is transformed as an effective and complete function in this model by satisfying service needs. Other functions in last systems are not affected and maintained in this system.

Multi-stakeholders have completed a preliminary fusion until now, but the system still has some problems. So we study the further fusion between stakeholders. The problem is within the scope of subsystem, depending on the application condition of Standard Solutions, so choose (3.1.2) standard solution—improve the connection in the double-system or multi-system.

Depending on the evolution route (2), we should enhance the utilization rate of the product. With this guidance, we change the way of cooperation between producers and users from selling to renting. In this way, user can keep the usage right but not the owning right, so we can make full use of products by optimizing distribution. The Su-Field model of further stakeholder system fusion is expressed in the Fig.7. Two-way solid arrows represent stakeholders function with each other. Solid frontier line represents that the integration formed between the stakeholders is sufficient function. The symbol ‘+’ represents the functions strengthen. Rental form makes the relationship between producers and users closer and extended to the usage stage, which extend enterprise social responsibility. Producers want to obtain more benefit so they will take more measures to lengthen the service life of product, which strengthen the interaction between producer and other stakeholders in the usage stage, and they become a whole gradually. This form can help provide users better service functions and realize core function more efficiently.

4. Instances

This literature will take the establishment of the car rental service system as the instance to verify one of the multi-stakeholders fusion models, the Su-Field model of further stakeholder system fusion. The establishment consists of two steps: First, determine the stakeholders in the car rental service system. At the second, establish the stakeholder fusion system diagram in the car rental service system depending on the fusion model.

4.1. determination of the stakeholders in the car rental service system

Determine the stakeholders according to the three dimensions of stakeholders. Lateral stakeholders include the raw materials suppliers, producers, logistics, car rental sides, users, car recyclers, manufacturers and so on. Lengthways stakeholders include car maintenance, car repairing and so on. Vertical stakeholders include environment, bank, insure company and soon.

4.2. Establishment of the stakeholder fusion system diagram

The diagram is expressed in the Fig.8. The diagram describes the stakeholder fusion from mainly four aspects: substance, information, fund, service support.

At first, according to the sustainable principles, it should ensure the rational use of resources and resources recycling and form a closed loop of substance flow through reasonable configuration among stakeholders. Based on the Su-Field model of further stakeholder system fusion, connect the stakeholders in the product life cycle in series. Raw materials suppliers are the starting point of substance flow, who transport the substance to the producers through logistics. Producer produce cars to meet the user needs through designing and manufacturing and transport them to the car rental sides from region to region. Cars will reach the finally users through car rental sides. Customers will return the car after using. When the car can’t work, it will be returned to the factory. Producers make them remanufactured through the cooperation with recyclers. Recyclers supply the remanufactured car to producers and collect the cars or components which can’t be recovered as preparation for raw materials. This flow route achieves sustainable goal. At the second, according to the principles meeting customer needs, it should ensure product usage quality by providing more technical service in the usage stage, to realize functions efficiently. It is considered sufficiently in the system design process. Based on the Su-Field model of further stakeholder system fusion, connect the lengthways stakeholders in parallel and form an integral service support system. Producers organize service processes such as product maintenance at the same time when they supply cars to the rental sides. In the maintenance process, the record is necessary and it will be provided to recyclers to help the detection in the
Fig. 8. Stakeholder fusion system diagram in the car rental service system
remanufacturing process. At last, according to the Su-Field model of further stakeholder system fusion, it should enhance utilization rate of the product by renting. When you buy a car, you don’t use it every moment actually, so it will be better that rent a car only when you need. Then the car will be used efficiently by different person in different time and one person’s different need for cars type in different scenes will be satisfied in this way. Provide targeted products can optimize the allocation of resources and can save energy largely. It make using cars convenient for customer that only provide operation performance of the car to the users and producers are liable for everything left such as remaining, insurance, recycling and so on.

The all system illustrates the flow route of substance, information, fund and the service support and the system operating mode clearly. It fully validates the feasibility of the Su-Field model of further stakeholder system fusion as the guidance to establish stakeholder fusion systems.

5. Conclusion

As the basis of stakeholder fusion, the determination of the stakeholders is studied in this literature and three dimensions are put forward. Then based on the ideality, we get the product service system evolution route pointing out the direction of the multi-stakeholders fusion. Analyze the stakeholder system with Su-Field model and combine Standard Solution and evolution route to determine the Su-Field models of stakeholder fusion. Finally, validate the feasibility of the Su-Field model of further stakeholder system fusion as the guidance to establish stakeholder fusion systems. Although this model promote the study of stakeholder fusion further, but also need be improved on the details in the future.

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Solution oriented bionic innovation method LOBIM – applied in automotive industry

Dipl. Ing. Nick Eckert*
Takata AG, Hussitenstr. 34, 13355 Berlin, Germany
* Corresponding author. E-mail address: nick.eckert@eu.takata.com

Abstract
The topic of the presentation is a simple merge of TRIZ with bionics. This method is called LOBIM (Lösungsorientierte Bionische Innovations Methode), a German acronym for solution oriented bionic innovation method. It based on the 40 innovative principles of TRIZ. The core message is that all 40 TRIZ principles have examples in the nature. So TRIZ principles are not only a solution library of technical problems extracted from patents. All 40 TRIZ principles are a part of the unknown amount of natural evolution principles. This statement will be proved in the presentation with many examples.

LOBIM has compressed the 40 principles to 38 and added 9 principles from bionic and evolutionary research. With this 47 abstract proposals engineers and inventors can get inspiration for real solutions in a very simple way. This solutions could be more eco-friendly and sustainable because of their natural roots.

It will be also explained one invention from automotive industry which was created with LOBIM.

Keywords: LOBIM, TRIZ, sustainability, bionic, automotive, evolution

1. Introduction
Innovation becomes more important in the global economy. Automotive suppliers are under rising pressure to innovate in shorter time. OEM platform strategies are leading to massive cost savings and standardization. For OEM’s is important to present new car-function and design innovations every year to be different and attractive for their customers. They push their suppliers to be inventive and to bring out new innovations in order to implement them into their cars. For a safety system supplier like TAKATA does it mean more innovation in safety, design and cost savings.

2. Experiences from TAKATA innovation process
The innovation process today takes place in a more and more reduced time frame. Most people can’t have new ideas under time pressure. But automotive engineers have less time for problem solving in daily business. That is the reason why classic brainstorming is so popular. If you have a problem to solve you can call some other engineers or management people to a brainstorming about this problem. Sometimes you have only one hour and sometimes a half day in maximum to create a new idea. Anyway it is important to use the short time very intensive for ideas creation. But often the outcome in classic brainstorming sessions was very poor. Always it depends on the mixture of participants and on group dynamic interaction. There is another important fact in brainstorming
sessions, how participants can separate themselves from daily business thinking. Can they think outside of the box?

In 2002 we began to look for a tool, which can help us to bring out new ideas in a short time. I found TRIZ and tried to apply it in an invention workshop. First time I used it with help of a working book. It was a disaster. After long discussion we were not able to define our main problem with contradictions. Many participants had to high expectations. They thought TRIZ will present a ready to use solution. And at the end of the day was a huge disappointment. In my point of view the reason of this big failure was not the TRIZ method itself but our lack of experience to work with. I attended on training courses were I learned more about the different TRIZ tools. Now it was much easier to use TRIZ in our innovation workshops and we got more and more success. The participants create a lot of good results but it was remaining difficult to meet workshop time limits. My workshop experience was that contradiction definition takes a lot of time (about 2-3 hours). The contradiction matrix has offered a selection of abstract solutions (innovative principles). But the amount of abstract solution proposals was very different. In some cases we found five and in others only one or sometimes nothing. But always the workshop participants have to translate the abstract proposals into a real world solution. This is the most creative part of the invention process. Often we had less time for this part because we wasted time at the beginning.

In special cases we were not sure to find the right contradiction. If we were wrong, we would have got wrong proposals from matrix. This uncertainty and the lack of time lead me to the conclusion to use all of the 40 principles as proposals (also described in [1]). Workshop participants should use all of them as an inspiration for a real world solution. We save time from contradiction definition and use this time to scroll all 40 principles for our solution search. This brought us a lot of new ideas in a short time.

3. LOBIM as a new method

In parallel of our first innovation steps with TRIZ, I was dealing with bionics as another innovation tool. It was fascinating for me to see the very efficient solutions used by natural plants and animals. I was keen to use these solutions for our engineering questions. So I was reading a lot of bionic literature and internet websites with passion. I could not found a clear ordered method to use bionic for engineering problems. But I found some main principles defined by the German bionic pioneers Werner Nachtigall and Frederic Vester [2]. These evolutionary bionic principles were partly similar to the 40 innovative principles from TRIZ. Integration, Multifunction, Live time limitation, Recycling and Feedback are part of Bionic and TRIZ. I was curious to explore more similarities in both systems and took a look into the big bionic compendium by W. Nachtigall [3] to compare the several of hundred bionic examples with TRIZ principles. It was possible to assign most bionic examples to the innovative principles from TRIZ. Most of them were more complex, so they had more than one TRIZ principle inside. But it was also visible that there exist some more natural principles than the 40 in TRIZ. I compressed the 40 into 38 and added 9 principles. But I am not sure how many exist overall. The result of my investigation was an Excel table with many of hundred bionic examples ordered in 47 innovative principles. These additional 9 principles are different from all known extended lists of TRIZ principles (for example in Matrix 2003 by Darell Mann et.al. [4]). Engineers get inspiration for practical solutions by thinking about all principles, not only a selection. I am working with the 47 principles in innovation workshops for many years and call it LOBIM. This is a German acronym for Solution Oriented Bionic Innovation Method. LOBIM is a merge of TRIZ and bionics in a way easy to use in daily business. In my book (Eckert [5]) which will be published this month I have described this in more detail.

There are some other interesting approaches to merge TRIZ and bionics which are based on the evolutionary and conflict aspect of them (Vincent J. et.al. [6], Günther [7]). But LOBIM uses only the innovative principles of both for inspiration. In my experience it is not so important to find the suitable abstract principle solution. It is more important to find a lot of inspiration for practical solution. In my innovation workshops participants are finding very fast to practical solutions by scrolling through all innovative principles, faster than with the use of classic TRIZ contradiction matrix. Following I will give an example for a revolutionary innovation in airbag design with help of LOBIM.

4. Development of a very small airbag design with LOBIM

Airbag designers are facing to strong package limitations for many years. There are more integrated control functions in steering wheels today. Space for the folded airbag cushion inside of steering wheels is getting smaller. But legal and consumer requirements for driver safety are getting harder. So there was no way to reduce the airbag cushion size itself. The machine force to press the folded cushion into airbag housing was on the limit. The airbag covers got too much stress so that tear seams became visible. This was a big negative quality issue complained by the customers. On our first innovation workshop we asked how to reduce package volume. We scrolled through the 47 LOBIM principles and got some inspiration. One of them was to evacuate instead of pressing air out of cushion package. This idea was inspired by the TRIZ principle of inversion. First we tried to suck the air by a vacuum cleaner out of the package during folding process in the machine. The impressive result was a package reduction of about 30%. But the package didn’t remain in form. It was still pressing hard to airbag cover. On our second workshop the question was: How can we fix this 30% reduced package? Here we got inspiration from the principle flexible surfaces. If we use a plastic wrap foil and isolate the airbag from environmental pressure we can fix vacuum and the reduced package. Our next prototype was manufactured with “Food saver”, a kitchen vacuum machine for food. With this innovation step we reached a further reduction of additional 10% and a compact airbag package which we could handle with more comfort in the production process. Now we hold a very compact hard package in our hands. But there was still
an open point remaining. During airbag deployment the extension force is very strong. How we can fix this package strong enough inside of airbag housing without damage of foil and evacuation. On the following LOBIM workshop got inspiration from the principle Local quality. We found eagle crawls in the collection of bionic examples. Crawls can fix strong but with some protection it can be soft enough to prevent loss of vacuum by foil destruction.

The final solution worked out in three main steps. All inventive steps used LOBIM as inspiration tool. A patent of this so called “Micromodule” was applied (No. DE102004056128A1) in 2004. “Apart from spectacular new steering wheel designs, the integration of small and compact airbag units also offers the chance of generating more space to integrate further functions such as vibration motors for warning the driver, additional switches, etc. On the other hand, a small, package- and weight-optimized airbag module contributes to the weight reduction of the vehicle finally leading to less gas consumption and CO²-emissions. Within it has proven that the vacuum folding technology has reached the necessary maturity degree for series production. This has already been awarded by some car manufacturers by placing concrete application orders at Takata.” [8] Meanwhile a lot of cars are on the road with this revolutionary technology. In 2011 Takata vacuum folding technology was honored by the Automotive News Pace Award for superior innovation, technological advancement and business performance.

5. Conclusion

We did many inventions like this in the last years with LOBIM. It is so successful because it is very easy to use and takes a minimum of time. LOBIM concentrates the engineer on pure creative work. It unifies the innovative power of bionic and TRIZ in an easy way. Today we are using www.lobim.de for innovation workshops. But LOBIM is only an inspiration tool for engineers. The main part of development process is still hard work and takes much more time than the creative moment.

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Case study: Half automatic coating of guide wire

Barbara Gronauer\textsuperscript{a*}, Thomas Schobert\textsuperscript{b}

\textsuperscript{a} StrategieInnovation, Rhönmalerring 30, 36088 Hünfeld, Germany
\textsuperscript{b} EPflex Feinwerktechnik GmbH, Im Schwoellbogen 24, 72581 Dettingen/Erms, Germany

* Corresponding author. Tel.: +49 6652 99 28 280; Fax: +49 6652 99 28 279. E-mail address: bg@strategieinnovation.de

Abstract

The project presented within this paper deals with the coating process for guide wires for minimal-invasive operations in the human body. In order to reach the required quality of the coating of guide wire, adaptations of the available dipping device should be made. In the first step, the description of the multiscreen-model and the concept of the ideal machine were used to clarify the task and the expectations of the company. Following that the problem was analysed by the cause-effect-chain analysis, the function analysis and the resource collection. Based on this knowledge and results gathered engineering contradictions and physical contradictions, inventive principles and separation principles were used and starting points for solutions to fulfil our demands were collected. The development steps have been worked through systematically and efficiently by using the TRIZ methodology. First of the solutions were realized successfully.

Keywords: TRIZ; coating device; dipping device; guide wires

1. The desired product

The company produces medically used guide wires, which are deployed worldwide. These special guide wires are provided for minimal invasive operations and serve as a guide to reach the desired places in the human body. To prevent injuries the tips of the guide wires should be soft and flexible.

Usually a guide wire consists of a soul and a coat (tube or spring). To get a soft tip one end of the wire is cut conically. This end has to be coated with a highly flexible synthetic material (Pebax), because the thin tip of the wire could perforate tissue. This synthetic material contains Wolfram, which can be made visible by X-rays. At last the coated wire tip and the remaining part of the wire must have the same diameter. The synthetic coating must be smooth and adhere to the wire.

Up to now these medically used guide wires have been successfully produced manually. Owing to an increasing demand the production of a higher number of units is required.

2. The existing and the further developed dipping device

2.1. The existing dipping device

From the point of cost efficiency, the available semi-automatic dipping device should be used. The following pictures show this existing dipping device and the clamping device for guide wires, which have already been used for the production of another product variant for a longer time.

Fig. 1. Existing Dipping Device, schematic sketch.
The clamping mechanism for the guide wire is pushed into the upper part of the installation. The 30 to 70 cm long guide wires hang down the clamping mechanism and are threaded into the perforated plate below. Underneath the perforated plate there is the narrow dip container with the coating liquid.

2.2. Description of manual coating process

During manual production, an employee dips a single wire into a bottle with coating liquid, pulls it out again and lets it dry spread out on a table for ten minutes. The speed of the movement and a little bushing within the bottle make sure that there is the desired wipe off effect of the Pebax- solution.

2.3. Description of the semi-automatic coating process

When the semi-automatic dipping device is used for this process, the guide wires are mounted into the available clamping device (2 clamping devices, each for 7 guide wires). The clamping mechanism with the wires is then inserted into the dipping device. The guide wires, hanging down from the clamping device, are then threaded into the perforated plate. Underneath the perforated plate a dip container with the coating liquid (consisting of Pebax and solvent) is moved up and down, so that the guide wires are dipped into the liquid. The bushing used for manual production cannot be applied here to wipe off excess coating liquid. Therefore a special installation for wiping off the redundant coating liquid was developed by the company.

The wiping device consists of two moveable parts with perforations and special cavitations for wiping off the coating liquid. However, the current design of the wiping device could not meet the required quality and productivity requirements, because different problems like the conglutination due to the wiped off and drying Pebax or bending of the guide wires because of imprecise threading through the holes occurred.

Therefore the company is currently searching for another solution for reaching an optimal quality as well as a reliable number of produced units. If it was impossible to find a qualitatively reliable and sufficiently productive mechanical solution, the guide wires would still have to be produced manually. Manual production however would raise the prize to a non-competitive level.

2.4. Allowable system changes

Because the company insists on using the available dipping device TA02, all considerations to influence or modify the working process in the supersystem have to be excluded. Nevertheless they were written down, because for an increasing demand for Pebax guide wires a new installation with a higher grade of automation is planned to be constructed.
Also, the existing clamping device for wire tips (picture 2) have to be used for the planned process. This clamping device can hold 7 wire tips and coat them all at the same time. The dipping device can take two clamping devices simultaneously. Minimal technical changes concerning the clamping device, the dip container or the linear guide are possible, and as far as they prove to be economical, they can be executed by the in-house tool shop. Additionally requirements were:

- only materials licensed for technical medicine can be used and
- the coating solution can’t be changed.

### 2.5. Criteria for choosing solution concepts

These are the most important criteria mentioned:

- time needed for coating
- costs for converting the installation
- inhaling fumes by the employees should be prevented
- reached number of units.

### 2.6. Ideality

A manual coating, on the one hand, secures that the desired diameter is reached, and that redundant material is wiped off by the bushing to prevent wrinkles and drops on the dry product.

\[
\text{Degree of ideality} = \frac{\text{Even Pebax-coating (0,75mm)}}{\text{high consumption of time, consumption of material, low number of units per employee}}
\]

In contrast to the current construction the realisation of the improved working process at the dipping device should include that the wiping device is supplied automatically with wires, which otherwise could not be coated. Furthermore, to avoid faults, there should only be one possible way for the wires to reach the dipping device.

\[
\text{Degree of ideality} = \frac{\text{Even Pebax-coating (0,75mm)}}{\text{Lower consumption of time, consumption of material distinctly higher number of units per employee, amortizing costs of investment}}
\]

### 2.7. Ideal machine

Two aspects have to be considered concerning the demands on the ideal machine:

1. The ideal machine produces a complete coating of the guide wires in a constant quality without additional costs for cleaning after the wires have been mounted into the clamping device, which then have to be inserted into the coating device. The coating liquid has to dry quickly on the guide wires, but stay liquid in the dip container.
2. That means, at the most, the clamping devices have to be exchanged by an employee. Additionally, the clamping device by its design should allow a failure free insertion, installation and clamping of the guide wires.

At that point the clarification of the situation was sufficiently done, and the problem analysis phase started.

### 3. Problem analysis

The problem analysis was performed by the following TRIZ-methods and tools:

- Cause-effect-chain-analysis
- Function analysis
- Resources.

#### 3.1. Cause-effect-chain-analysis

The test results with the special wiping device as described above showed the following disadvantages:

- a) wire hits wiping device
- b) coating blocks up wiping device
- c) wire cannot find bushing
- d) wire blocks up wiping device

To solve these problems the key problems were identified by the cause-effect-chain-analysis.

#### 3.1.1. Cause Effect Chain 1

**Wire hits wiping device**

![Fig. 5. Cause-effect-chain-analysis for „wire hits wiping device“](image)

The company is using a universal clamping system for their clamping device, because its function is easy to be understood by unskilled employees without further training and the clamping device can be used for the production of several product variants. The discussion pointed to the fact that the clamping device had too much tolerance, which led to more or less tension and bending of the inserted wires. Consequently they are not always inserted vertically, but in different directions, and they do not always reach the desired spot for wiping, sometimes they even miss the perforation of the wiping device distinctly.
3.1.2. Cause-Effect Chain 2

Wire cannot find bushing or blocks up wiping device

Two aspects are shown here:

a) The In-house-tool manufacture did not work exactly, as the perforations for the guide wires were not always exactly in the middle, so that even guide wires which had been inserted precisely, could not find their perforations.

b) The perforations were used as bushings. Therefore their diameter was the same as the diameter of the bushing used for manual coating. The wiping device should be closed around the guide wires for the dipping. But because of the small size of the perforations and the not straight insertion the guide wires missed the perforations of the wiping device and blocked it up. For using this wiping device it has to be opened, the wires have to be threaded manually into the perforations, and then the wiping device has to be closed again manually.

3.1.3. Cause Effect chain 3

Another reason, why the wires missed the perforations, could be the fact that the wires had no guidance in the bushing besides the clamping at the above end. This point was not considered here, because it was assumed that the uncoated wires are mounted vertically in the clamping device.

3.1.4. Cause Effect chain 4

Coating blocks up wiping device

A further disadvantage of the current solution was the fact that the wiped off coating solution sticks to the wiping device and eventually blocks the perforations, because the room temperature stimulated evaporation of the solvent as the machine was not a closed system with a lower temperature than the ambient temperature. Besides there was no alternative solvent with less vapour pressure. A higher room temperature also resulted in a faster drying process, and of course, the employees felt better with a pleasant room temperature.

3.2. Function analysis

For a more detailed problem analysis a function analysis was performed to locate the problems in the dipping device more precisely.

Main function of the dipping device: guide wire holds coating solution. The Target is the coating solution.
After modelling the system in its useful state, the problems - also analysed in the cause-effect-chain-analysis - were modelled as function disadvantages:

c) wiping device stops/bends guide wire (harmful interaction)
d) wiping device guides wire insufficiently (insufficient interaction)
e) wiping device holds coating liquid (harmful interaction)
f) missing interaction between wiping device and guide wire (wire cannot find bushing).

Fig. 9. Function Model of dipping device including function disadvantages

These are the questions deduced from the function analysis:

- How could be prevented the bending of the guide wire by the wiping device?
- How could the wiping device guide the guide wire more efficiently?
- How could be prevented the wiping device from holding the coating solution?
- How could be made sure that a useful interaction (e.g. guiding) is established between the wiping device and the guide wire?

The main points of the cause-effect-chain-analysis as well as the questions of the function analysis showed us the direction for formulating the problem models.

3.3. Available resources

To use the full potential for the search for solutions the available resources were collected.

The dipping device is located in a cleanroom and is therefore exposed to the same surrounding conditions all year. The following resources are available:

- compressed air
- power
- UV-light
- consistent ambient temperature
- air
- power
- NiTi
- Pebax-solution
- linear guide
- wiping device with different perforation sizes
- humidity
- gravitation
- heating device of other devices in the room
- unused room
- employee

4. Finding of solution

During the problem analysis it was clear that the main problems were based on the design of the wiping device, the drying properties of the coating liquid and the possible imprecise clamping of the guide wires. With the results of the problem analysis the phase of idea generation and solution finding based on TRIZ problem models and solution principles were started.

In the next step, Engineering and Physical Contradictions from the current results of the problem analysis to aim at the wiping device were deduced.

4.1. Formulation of Engineering and Physical Contradictions concerning the wiping device

EC 1: If a wiping device is used redundant material is wiped off, but the wires are prevented from dipping into the coating solution.

EC 1 inverted: If no wiping device is used, wires dip into the coating solutions without problems, but redundant material is not removed.

EC 2: If a wiper is used the wire tip will be fine, but the wiper will be agglutinated.

EC2 inverted: If no wiper is used the wiper will stay clean, but the tip gets wrinkles.

This boiled down to the following physical contradictions:

PC 1: The system dipping device should have a wiping device to receive a fine tip, should not have a wiping device to prevent attaching.

PC 2: The system wiping device should have wide perforations, so that the
wire can easily penetrate, should have narrow perforations, so that the redundant coating liquid can easily be wiped.

4.2. Formulation of contradictions regarding the drying and sticking of the coating liquid

Engineering contradictions
EC 2: If the system is cooled, the coating does not dry, but the coating remains too damp at the wire.

EC 2 inverted: If the system is heated, the coating on the wire dries well and fast, but the coating liquid blocks up the wiping device.

Physical contradiction
PC 1: The system dipping device should be cool, so that the coating stays liquid and the wiping device keeps clean. Should heat up, so that the coating on the guide wires can dry well.

The noted contradictions were worked through by using separation principles and the 40 inventive principles. All single ideas were drawn or written down, together with sketches and concept drawings.

5. Solution Concepts

The evaluation of the single ideas lead to two solution concepts that were proposed and discussed with the tool manufacture for feasibility.

5.1. Concept A:

Pressurized air (available Resource) is used to blow off excess coating liquid after the wires have been dipped into the solution. The air stream should come from all sides to achieve an even coating thickness, thus a ring-shaped “pressure sleeve” that surrounds the guide wires and is positioned directly at the openings of the perforated board was proposed. These sleeves feature small openings through which the air is blown. Additionally, the air improves the drying process (forced convection) at the coated guide wire, so the overall temperature of the coating liquid in the container can be lower, preventing clogging and sticking of the liquid. Additionally, the stream of air could be designed as a spiral, cyclone-like stream for even coating and cooling of the solution at the guide wires.

5.2. Concept B:

A wiping device consisting of wedge shaped funnel-bushings is proposed with a 1mm opening at the bottom and a larger opening at the top (separation of big and small hole in space). The funnel-bushings are positioned in the holes of the perforated board and with their funnel-shape provide an effortless “self-guiding” of the wires, even if they are not mounted exactly straight in the clamping device. The small opening at the bottom executes the wiping-function.

Concerning the danger of drying coating liquid blocking the opening, a re-formulated function model of the problem zone revealed, that there should be no possibility for the solvent to evaporate in the area where the wiping happens.

Concerning the concept of ideality and using resources lead to a concept where the coating liquid itself stops the air from moving/”extracting” solvent from the coating liquid. Thus the lower part of the funnel-bushings were designed to be placed inside of the coating liquid, so no air is available in the area of the small wiping hole, preventing drying and conglutination in this zone.

5.3. Selection of solution concept

The solution concepts were discussed with the in-house manufacture regarding feasibility. Concept A was rejected as...
being too complicated and expensive for in-house manufacturing. Concept B was chosen, and 14 funnels were produced, so that each funnel - sitting in the perforated plate with seven perforations per side - takes in one guide wire. Featuring a wide opening on one side, the funnels make sure that there is enough space for imprecise hanging in the clamping device, whereas at the same time the funnel shape guides the wire evenly to find the narrow perforation at the bottom that takes care of wiping off the coating solution.

The funnels were initially tested in a manual test-run. The test showed very even and satisfying results. The testing of the funnels mounted inside the dipping device has still to be prepared by the tool manufacturer.

6. Current state of the project and future prospect

The resulting ideas and concepts are in a pilot project as indicated by the companies guideline mentioned at the beginning of this paper.

As a future development (depending on order volumes) a newly designed, automatic dipping device might be designed using the solution concepts provided through this work with TRIZ-tools.

References

Abstract

Reliability testing is an indispensable requirement in product and process development. Classical test procedures are time and resource consuming which contradicts the current trend of shorter innovation cycles. The article focuses on two issues:

- The systematic development of accelerated test procedures for expected failure modes and the possibilities to demonstrate improvements compared to the previous status.
- The systematic research for unexpected failure modes (masked failures and unknown failures).

In the first case the cause and effect relationship is used to identify the limiting factor for the failure reproduction in the test. TRIZ is going to provide the set-up for appropriate tightened conditions for this purpose. In the second case the cause and effect relationships may localise possibilities for failures which are currently not in focus.

In both cases a combination of TRIZ (or its quality assurance toolset AFD) and reliability engineering is used to design appropriate test procedures. The test procedures can be used to validate the cause and effect model for the failure. TRIZ (AFD) offers the possibility to eliminate the failure or at least reduce the effect of this failure. Reliability engineering can provide the evidences.

Keywords: TRIZ, AFD, reliability engineering, TOC, test procedures, accelerated tests, tightened test conditions

1 Introduction

In the recent years innovation cycles became significantly shorter. Furthermore, the legal requirements and customer expectations on product reliability substantially increased [1]. Industry is requested to react on this trend by reliable products within shorter time to market periods.

Real time and slightly lapsed real time tests are widely used in many industrial branches [2] [3]. The criterion for passing the test is defined as the endurance over a distinct period in time, a distinct operation time or a distinct number of operation cycles. ‘Test to fail’ is an alternative which provides additionally the time to failure and by the examination of the failed parts information about the causes for the failure. Statistically significant conclusions are consumptive regarding time and resources. Accelerated life time tests afford less time and resources [4]. The shorter time to failure and the substantially shorter feedback-loop are advantages. Disadvantageous can be missed failure modes or pseudo failures as a consequence of inappropriate test lay-out.

This paper presents a TRIZ supported procedure to map the failures that may occur to the system and to develop a test approach to assess and improve the system reliability. This approach is less time and resources consumptive. The additional risks by missed failure modes or pseudo-failures modes shall be minimised.
2 Basic Approach

Failure modes for a new system that will occur in the field can be classified into three classes:

- **Known failures from previous systems**: the cause and effect relationship is the same or almost the same as in the previous systems and known or almost known.
- **New failures**: failures have been previously unknown or unexpected. Important contributors to new failures are new components, new features or new functions.
- **Masked failures**: failures that are superimposed by failures that occur earlier and more likely. Masked failures will become predominant after the elimination of the previous failures.

The target of this approach is a ‘test to failure’ test concept to detect and assess all substantial failures, possibly with least expenditure of time and resources. The failure types mentioned above will lead to different proceedings to determine an appropriate test.

Reliability engineering [1][2][3] distinguishes four classes of failures according to their temporal occurrence:

- **Early failures** occur most likely in the early life of the system. Generally, early failures can be attributed to weak assembly or weak design.
- **Random failures** can occur at any point in time with the same likelihood. Random failures can be attributed in most cases to hazardous impacts from the environment, for example false operation by the customer.
- **Wear-out failures** occur predominantly in the late age of the system and can be attributed to harmful processes that develop over life-time, as abrasion, contamination, corrosion or decomposition.
- **Delayed failures** occur after the loss of protection against harmful impacts, for example corrosion after the loss of a protecting varnish layer or abrasion after the loss of lubrication.

Early failures are characteristic for emerging systems. Random failures, wear-out failures and delayed failures become predominant for mature systems. This classification by reliability engineering supports the definition of an applicable test.

2.1 Failures known from previous Systems

Known failures modes from previous systems can be explored in detail by historic field and lab data, so that the following information is available:

- The likelihood for a distinct failure mode depending on time in operation,
- The cause and effect relationship that characterises the failure mode,
- The pattern of the failure mode that has been profoundly described by the investigation of failed parts.

The knowledge of the interaction between the failure causing elements is a prerequisite for an appropriate test. Failure tree analysis is a well accepted tool to monitor the fundamental cause and effect relationship. Advantageous is the application of the cause and effect diagram in TRIZ as outlined by Terninko, Zusman and Zlotin [5]. Additionally, this proceeding offers the possibility to find appropriate measures to counteract the failure mode after reproduction in the test.

Known failures will be dragged into any new system unless there is a change to its elimination or at least to its extinguation. In order to demonstrate an improvement regarding a failure mode its reproduction under test conditions is necessary at first. Later-on the evidence of an improvement has to follow.

2.2 New Failures

In proactive failure management the FMEA is a well established tool to detect and to assess potential new failure modes. As the FMEA is based on the participants’ failure awareness, it is restricted to possibilities in the participants’ scope.

The FMEA limitations can be overcome by the failure prediction tool of AFD. AFD uses the TRIZ approach to point out potential new failure modes which may be associated with a new system. The cause and effect relationships can be used to design the test. The test shall verify the supposed failure and provide the information about time to failure under tightened conditions. In a later step the test can be used to demonstrate improvements.

As new failures are expected in connection with new components, functions and features the proceeding shall be restricted on new system elements and its cross-correlations with previous system elements.

2.3 Masked Failures

Masked failures become present after the elimination of previously dominant failures. As masked failures primarily are out of focus, their detection and assessment is difficult.

Masked failures can be identified as rare or late in life-time incidents by failure records. The exploration of masked failures by retroactive AFD analysis pretends to be more effective.

3 Procedure of Test Development

The starting point for a test concept development shall be a complete list of potential failure modes expected to occur. The second step is the prioritisation of failure modes in order to determine the succession of test development. The next steps are the development and the realisation of an appropriate test method for each major failure mode.

The cause and effect relationship for each failure mode is an indispensable prerequisite to develop a test. All elements important for the failure formation should be taken into account. For new and masked failures preceding investigations and iteration steps may be necessary.

In order to reproduce the failure under tightened test conditions (failure inversion in AFD terminology) the element which constrains the formation of the failure shall be identified.
This element represents the constraint in the context of TOC [6] and the so-called focal element in AFD [7] [8]. For a tightened test the constraint at the focal element shall be removed or at least extenuated in order to empower the test.

There are a variety of options to treat the constraint at the focal element, for example: increase the temperature to accelerate thermally activated processes, increase mechanical, physical or chemical load to accelerate harmful processes. The TRIZ tools concept of resources and the list of physical and chemical effects may provide valuable hints for this purpose.

The tightened focal element must be fully supported by the adjacent elements of the cause and effect representation. The adjacent element realisation can be different from the original application. As the conception of a special test bench is advantageous, it is essential that the effects on the focal element are almost equivalent as in the real application.

The criterion for the adequacy of a test shall be the reproduction of the failure mode pattern under test conditions. This requirement minimises the risk of pseudo failure detection. For new failures modes the expected pattern can be regarded as sufficient.

The risk of missed failure modes can be minimised by maintaining the global approach of this concept. – All known and possible failure modes shall be represented by an appropriate test.

TRIZ and AFD offer a variety of possibilities to eliminate or at least extenuate the effect of the failures. This proceeding is not in focus of this paper. Nevertheless, it is part of the test design to establish criteria to declare a test as passed.

- In the ideal case the failure causing element is eliminated. The test can be regarded as passed if the failure does not recur after improvement.
- In other cases the observation of the failure mode is considerably less likely or delayed. In this case the proof can be provided by reliability statistics. The improved parameters can be used to estimate the improvement under real conditions.

The standard classification of failure modes in reliability engineering can help to identify the focal elements and the layout of the test.

### 3.1 Conventional Approach for Early Failures

Early failures are in the immediate focus after introduction of a new system because they become obvious in a short distance of time. In most cases the causes are weaknesses concerning assembly, design or maintenance. As these failures very quickly occur, tightened tests pretend not to be necessary for the failure reproduction and the demonstration of any improvements.

### 3.2 Special Approach to assess Random Failures

Practically all random failures occur due to occasional exterior conditions, for example misuse by customers, extraordinary circumstances or rare events. In nearly all cases these exterior conditions are hardly present under conventional (previous) test conditions. The analysis shall concentrate on these special incidents as potential focal elements.

The tightened test shall comprise an increased likelihood and an intensification of these conditions for random failures.

### 3.3 Special Approach to assess Wear out Failures

Wear-out failures occur if an occasional or a permanent stress has a harmful impact to the system (mechanically by abrasion, permanent or alternating over-load; geometrically by agglomeration of deposits, chemically by reaction (in nearly all cases: corrosion) or physically by material decomposition. It shall be mentioned that there are hardly any other wear-out mechanisms. For test tightening purposes the wear out mechanism shall be identified as the focal element. For unknown and masked failures the system shall be explored with focus on the above mentioned wear-out impacts. Specific measures to intensify wear-out are increasing temperature or the mechanical, physical or chemical load.

### 3.4 Special Approach to assess Delayed Failures

Delayed failures are very often correlated with the loss of a protection mechanism, as protective layers or lubrication. A tightened test for delayed failures has to stress the protection mechanism in a way that reflects the real application. Cause and effect diagrams will be useful for this purpose. Focal element would be the stress on the protective element.

### 4 Conclusions and Outlook

The main idea of the test concept is the classification into failure modes. Singular tests are specially designed to assess each distinct failure mode. Mutually together the tests demonstrate the failure behaviour of the entire system, except the failures that may happen at previously not considered interfaces. In order to map these failures a substantially reduced amount of real time investigations remain necessary.

The test concept offers the possibility to assess the failure behaviour of modular kits as widely used in automotive industry. In this case already developed and released components are used to design a new car models. This test concept offers a variety of advantages, regarding cost and time savings during the development without an impact on the information quality. Furthermore, modular kits offer a variety of advantages in the supply chain during mass production. One disadvantage seems to be obvious. Potential failure modes may cause a disaster because the entire fleet can be concerned. Tightened tests allow an enhanced debugging of the components and a short term improvement of the system.

### References:


[2] VDA Quality Management in the Automotive Industry, Reliability Assurance at Automotive Manufacturers and Suppliers (currently only available


Abstract

VDI Guideline 4521 Part 1: “Inventive problem solving with TRIZ: Part 1 – Fundamentals and definitions” has been published on 2015-04-01. The standard will sharpen the image of TRIZ, facilitate cooperation, and support studying and teaching. It is not a textbook but concisely summarizes basic assumptions of TRIZ and its terminology. It gives an overview on specific methods and tools which will be described in the following parts.

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Keywords: VDI 4521; standard; standardization; terminology; TRIZ

1. Introduction

The methodology of TRIZ dates back to the year 1948 when G.S. Altshuller and R. Shapiro recommended it in a letter to the General Secretary of the Soviet Union, J. Stalin. It was first published in a paper dated 1956 [1]. TRIZ was further developed by a limited number of researchers, thereby including additional tools and ideas as from Value Analysis and Synectics [3]. The theory of the methodology was accordingly adjusted. After the border of Warsaw-Pact became permeable, TRIZ schools were established in various parts of the world and new methods and tools evolved. Together with the need to translate terminology between different languages, this caused evolution of a variety of terms and variants of tools. By the year 2007, different terms were being used for the same subject and different subjects are called by the same term. This situation is productive on one hand but associated with disadvantages on the other:

- For students of TRIZ, it is difficult to compare different sources of literature to deepen their understanding.
- Beginners tend to confine themselves to single parts of TRIZ and may misunderstand the whole theory.
- Wrong conceptions of TRIZ will come up and will get passed on and multiplied.
- If the theory is not well understood, methods of TRIZ will get mixed up with other theories and their original conception may get lost.
- Users and researchers need exchange and discussion. For this purpose, they need a common language and understanding.
- In order to present TRIZ as a state-of-the-art methodology which ought to be part of technical education, TRIZ should have a generally accepted body or core, i.e. a standard.

TRIZ masters Litvin, Petrov, and Rubin therefore compiled a Body of Knowledge in 2007 [4]. This work is now leading to a standard in several parts with a – hopefully – broad...
Impact. After various discussions within the TRIZ community at MATRIZ and ETRIA conferences 2013 and 2014 [5] and on www.linkedin.com as well as in cooperation with the association of engineers, VDI, we have edited a first part of this document. It has been published in blueprint as VDI 4521 Part 1 (www.vdi.eu/4521) on April 1st, 2015. Objections could be filed until Sep 30th, 2015. The process of this work is being continuously presented and discussed with the international TRIZ community. In the year 2020, the standard will be revised. This does not exclude the possibility of discussing its contents in the meantime.

2. VDI Guideline for TRIZ

VDI was founded in 1856 and represents 150,000 members world-wide [6]. VDI states its mission as acting for engineers and engineering in society. Besides this, VDI is a major organization setting technical standards. There are some 2000 valid VDI Guidelines (i.e. standards) at this moment [7]. Characteristics of these standards are:

- VDI guidelines are made by engineers for engineers in honorary (unpaid) work.
- VDI guidelines describe the state of the art – that is, only approved knowledge can be standardized.
- VDI guidelines are generally approved technical rules.
- The majority of the guidelines are multilingual.
- After 5 years, every standard is re-evaluated. If the state of the art has changed, the standard is removed or updated.
- In contrast to ISO, CEN or DIN standards, VDI guidelines are not set by companies but by individual experts who decide with one consent.
- Cost of standardization work is covered by selling the standards via Beuth Editions, Berlin.

The main reasons why VDI was chosen for cooperation were the international reputation of TRIZ standards and the way of working in a group of individual experts without economic interests of any party. A certain drawback may lie in the fact that VDI claims the copyright for the product and does not permit freely circulating it among users. In terms of TRIZ, this constitutes the contradiction “The standard shall be a VDI standard in order to enjoy VDI quality but it shall not be a VDI standard in order to be freely available”.

Several concerns were raised over setting a standard on TRIZ which were discussed in [5]. The main fears expressed concerned a possibility of restricting the free use and further development of TRIZ. A VDI standard, however, only describes one – generally approved – way of designing objects or performing work. It does not hinder anyone from doing his work in other ways. On the contrary, any TRIZ user may refer to VDI 4521 and point out in what way his result differs from or is better than the standard.

3. Work Schedule

The first meeting of the guideline committee took place on Oct. 10th, 2013 on which one of the authors (Hiltmann) was elected chairman of the board. The preparative work was described in [5]. V. Souchkov was preparing a collection of TRIZ terms in English [8] with short explanations, based upon the Body of Knowledge [4] among other sources. The committee, Table 1, first decided upon the structure of the standard:

- Part 1 – Basics of TRIZ and definitions of fundamental terms
- Part 2 – Modelling the Problem
- Part 3 – Solving the Problem

Parts 2 and 3 will concisely describe the tools used for the respective goals. Along with this, the terminology related to the tools mentioned will be defined.

<table>
<thead>
<tr>
<th>Table 1. VDI 4521 Part 1: Members of Committee. “VDI”: VDI member</th>
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<tbody>
<tr>
<td>Robert Adunka, Erlangen (vice chairman)</td>
</tr>
<tr>
<td>Alexander Czinki, Aschaffenburg</td>
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<tr>
<td>Barbara Gronauer VDI, Hünfeld</td>
</tr>
<tr>
<td>Kurt Götz VDI, Würzburg</td>
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<td>Michael Hartschen VDI, Wangen (CH)</td>
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<td>Claudia Hentschel VDI, Berlin</td>
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<td>Kai Hiltmann VDI, Coburg (chairman)</td>
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<td>Norbert Huber VDI, Weidenbach</td>
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<td>Karl Koltze VDI, Krefeld</td>
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<td>Pavel Livotov VDI, Offenburg</td>
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<td>Rainer Lohe VDI, Siegen</td>
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</tbody>
</table>

A subcommittee consisting of R. Adunka, K. Koltze, P. Livotov, O. Mayer, and C. Thurnes worked through V. Souchkov’s list and prepared a proposal on which terms should be regarded as fundamental and which as related to specific tools. Double terms were merged into one, their definitions were edited so that they would each fit into a single sentence, and German translations were sought in accordance with the most established terms in existing literature [9]–[17]. The procedure has also been described in [5]. K. Hiltmann contributed general information on TRIZ.

The whole committee would then discuss the results on several meetings which resulted in changes of various parts of the work. The whole process took approximately one year, seven meetings of the whole committee at different locations in Germany, and many nights of work of the subcommittee.

After passing the blueprint version of part 1, work was started on parts 2 and 3, Table 2. Not yet decided to date is the question of what further languages the standard shall be translated to. The committee strongly favours a Russian edition; its realization will depend on the editor’s market expectations. Other languages such as French, Korean, Malaysian and Farsi (Iranian) would be desirable as well.

The contradiction mentioned above (free accessibility) may possibly be solved using Innovative Principle 26 (use a copy). We will therefore check out if we can edit secondary literature, i.e. a paper about the standard, which we will make public free of charge.
Table 2. Topics of Parts 2 and 3

<table>
<thead>
<tr>
<th>Part 2 Description of Objective, Problem Definition, and Priorization of Solution</th>
<th>Part 3 Solution</th>
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<td>Principles of separating Contradictory demands</td>
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<td>&quot;Smart little people&quot; model</td>
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<td>ARIZ</td>
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4. Contents of Part 1

The standard is structured into three main sections:

- (1) Scope: describes the intention of VDI 4521 in accordance with the disadvantages of the current situation as named above.
- (2) Terms and definitions: lists the fundamental terms of TRIZ together with a short (one sentence) definition of each term.
- (3) Basic principles: short description of the fundamentals of TRIZ with subsections
  - (3.1) Solution structure and contradiction approach: TRIZ in relation to general problem solving, the contradiction approach, and system orientation.
  - (3.2) Use of TRIZ: Concrete problem → model building / TRIZ generalization → general solution → concrete solution
  - (3.3) Generic problem solving process with TRIZ: Example of applying TRIZ in the process of product development with steps to be taken, intermediate results, and suitable TRIZ tools.
  - (3.4) Basic assumptions of TRIZ: Short explanation of ideality and ideal final result as well as principles of the evolution of technical systems.
  - (3.5) Tools of TRIZ: Table of tools which will be explained in parts 2 and 3

5. Further Work

Definitions – the work of composing the standard comprised defining terms. The committee has generally used definitions which are widespread in the TRIZ community. There were however some terms which caused considerable discussion. Among these were the terms

- “function”: “Influence from a system or a system component upon one or more others which changes, eliminates, or maintains a parameter of the other component or system.” – Since the influence from one system component acting upon another is an influence inside the system, it is a function of the system upon itself. Moreover, in practice, the correct formulation of functions appears to be a task nearly impossible to the average user. Evidently, the theory does not explain well what exactly a function is. We therefore see some need for elaboration of function theory in TRIZ.
- “field”: “Effect onto an object which influences, i.e. changes or maintains, properties of the object.” – Ikovenko [18] and Feygenson [19] define a field as “an object without rest mass that transfers an interaction between substances” which seems to be logically consistent with Functional Analysis and may be better suited but is very hard to imagine. Anyway, the relation between function and field is not clear.
- “technical system”: “Man-made assembly of several interacting elements which meets a purpose.” – Do not all man-made objects meet a purpose – at least to please their creator – and does not an anthill or a woodpecker’s nesting hole meet a purpose as well? As it seems, technical systems are not necessarily man-made.

Other terms do not seem to be quite satisfying, e.g. “resources”: It has – probably in consent with the international TRIZ community – been defined in an unspecific way as “means suitable for the solution of a problem”. However, how does this fit into the TRIZ ontological system of systems, components, functions, and fields? Lyubomirskiy [20] presented new and very valuable work on resources on TRIZfest 2014, so some clarification of the nature of resources seems desirable.

TRIZ and other methodologies – the committee debated over the question to what degree the guideline on TRIZ should be regarded as separate from or related to other methodic systems such as VDI 2221: Systematic approach to the development and design of technical systems and products and Value Analysis (VDI 2800 et sqq.). It was decided to keep it separate in general, only mentioning other guidelines. This is in contrast, though, to the aim of VDI to cover all areas of technology and to relate and harmonize guidelines with each other. Moreover, TRIZ has profited earlier from outside stimuli like Synectics which led to the “Smart Little People” model and Value Analysis (VA) which influenced Functional Analysis as well as the Laws of Engineering Systems Evolution. One very promising concept is seen in the FAST functional diagram [21,22] which may potentially contribute to further develop TRIZ system theory. TRIZ and the user might finally benefit from harmonization of terms used in different contexts. One of the authors has therefore joined the committees of VDI 2221 and VDI 2803: Functional Analysis (notably for VA). Even though it may not be necessary to adapt terminology – which, in case of VA happens to be rather cumbersome –, it will be worthwhile to rethink the models made by other methodologies in terms of TRIZ.
TRIZ education – the work on the standard has been presented on TRIZ Developers Summit [23]. Although VDI 4521 addresses terminological issues which is expected to facilitate teaching and studying the subject, the participants pointed out the need of establishing teaching standards for TRIZ as well. Work is therefore being done in preparing exemplary training courses and accreditation criteria for TRIZ education.

6. Conclusions

VDI Guideline 4521 Part 1: “Inventive problem solving with TRIZ: Fundamentals and definitions” has been published in blueprint on 2015-04-01. The standard will provide a basis for common understanding of terminology and concepts without hindering further development and intentional deviation from this basis. Discussion on the standard among TRIZ users should be encouraged for deeper understanding and further development of the theoretical background of TRIZ. Any shortcomings which may be observed during the application period will be corrected in the following edition.

References

The application of 14 inventive principles of TRIZ to mathematical problems

Michal Hoča*, Milan Jurči, Štefan Medvecký

*University of Žilina, Univerzitná 2, 010 26 Žilina, Slovakia, 
†University Science Park of University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia

* Michal Hoč. Tel.: +420-949-880-685. E-mail address: michal.hoc@gmail.com

Abstract

In the Theory of Inventive Problem Solving (TRIZ) there is a set of 40 inventive principles that are applied to solve various technical contradictions. In this article, we would like to share our experience on how to benefit from the TRIZ using selected principles in solving of mathematical problems. The problems we selected are relatively simple, but yet very demonstrative.

Our goal is to introduce the TRIZ principles to mathematicians. The author of TRIZ is a soviet engineer Genrikh Saulovich Altschuller.

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Keywords: TRIZ, 40 inventive principles

1. Introduction

Soviet scientist, Genrikh Saulovich Altschuller, developed theory of inventive problem solving (TRIZ) in the 1950’s. Since then it has widely applied in resolving of technical contradictions. There are 40 inventive principles that are advising solver areas where to search for the most appropriate solutions. In this article, we would like to pick several inventive principles and show their application in mathematics. The list of the selected principle is following: segmentation, taking out, asymmetry, merging and combining, universality, nested doll and preliminary action, other way round, partial or excessive action, curvature, another dimension, feedback, intermediary and copying.

The problems that we are applying inventive principles to are simple and clear to understand. Although we did not manage to find application of all 40 inventive principles in mathematics, we would like to advise the interested scientists to have a look at the complete list of TRIZ principles – see [1].

2. Principle 1: Segmentation

The segmentation principle advises the solver to “Divide an object into independent parts. Make an object easy to disassemble. Increase the degree of fragmentation or segmentation.” [1]

We will demonstrate the use of this principle in the solving of the following task. Let us consider equilateral triangle, which we have to divide into four equal parts. Then exclude one of the four segments. The obtained trapezium has to be divided again into four equal parts.

The solution to this problem can be obtained by further segmentation of the trapezium. Now, it is straightforward to select the four equal parts from the segmented trapezium Fig.1.
Although our example is mostly graphical, the segmentation principle is used in solution of complex problems by dividing them into several sub-problems that are easy to solve one-by-one (part-by-part).

3. Principle 2: Taking Out

The taking out principle advises: "to separate an interfering part or property from an object, or single out the only necessary part (or property) of an object." [1]

We will demonstrate this principle in solving of integrals using the Per-Partes method. As the name of the method indicates the solution is obtained "by parts". We will consider a compound function in integral as a product of two separate functions. Then we can apply the well known Per Partes formula. For example:

\[
\int x \ln x \, dx = \left[ u = \ln x \quad v' = x \right]\frac{u'}{x} = \frac{x^2 \ln x}{2} - \frac{x^2}{4} - \int \frac{1}{2} \frac{x^2}{2} \, dx = \frac{x^2}{2} \ln x - \frac{x^2}{4}
\]

In the next example will evaluate the partial derivative of a function at a certain point. Firstly, we will restrict ourselves only on a variable with respect to which we would like to differentiate the function. This variable is “taken out” and the remaining variables are considered to be constant.

Let us consider a function:

\[
f(x, y) = 9 - x^2 - y^2
\]

We are seeking the partial derivative of this function with respect to x and with respect to y.

\[
\frac{\partial f(x,y)}{\partial x} = -2x \quad \frac{\partial f(x,y)}{\partial y} = -2y
\]

The gradient of our function f(x,y) has got a following form

\[
\nabla f = \left( \frac{\partial f}{\partial x}, \frac{\partial f}{\partial y} \right) = (-2x, -2y)
\]

The direction derivative of the function f(x,y) along the unit vector (in the plane xy) \( \mathbf{n} = (n_x, n_y) \) is defined as a dot product of this vector with the gradient of the function f(x,y):

\[
\mathbf{n} \cdot \nabla f
\]

The geometrical meaning is following: if we move in the direction of x axis for \( n_x \) and in the direction of y axis for \( n_y \), then the movement along the z axis (in a tangent plane) will be exactly for the value of direction derivative.

The tangent vector to the function f(x,y) can be expressed:

\[
(\mathbf{n}, \mathbf{n} \cdot \nabla f) \equiv (n_x, n_y, n_x \frac{\partial f}{\partial x} + n_y \frac{\partial f}{\partial y})
\]

In our specific case that is:

\[
(n_x, n_y, -2n_x x - 2n_y y)
\]

The next image Fig. 2 shows the tangent line to the function \( f(x,y) \) which is characterized by tangent vector \( (0,1,-2) \) in the direction \( \mathbf{n} = (0,1) \) in the point \( A[1,1] \):

4. Principle 4: The asymmetry principle in Fourier transformation

The asymmetry principle says, “Change the shape of an object from symmetrical to asymmetrical. If an object is asymmetrical, increase its degree of asymmetry.” [1]

Let us consider Fourier transformation:

\[
\hat{f}(x) \sim \int_{-\infty}^{+\infty} f(x)e^{-i\omega x} \, dx
\]

Does not converge for every function \( f(x) \). For example the Fourier transformation

\[
\hat{H}(\omega) = \int_{-\infty}^{+\infty} H(x) e^{-i\omega x} \, dx = \int_{0}^{+\infty} e^{-i\omega x} \, dx
\]

of a unit step function

\[
H(x) = \begin{cases} 0 & \text{pre } x < 0 \\ 1 & \text{pre } x \geq 0 \\ \end{cases}
\]

does not converge since the following limit does not converge:

\[
\lim_{x \to \infty} \exp(-i\omega x).
\]

Introducing infinitesimally small “asymmetry” \( \sigma \to 0 \) into the argument of exponential function \( i\omega \to \sigma + i\omega \), changes not only transformation name but also the convergence of Laplace image of unit step function:

\[
L[H(x)] = \exp(-\sigma) \exp(-i\omega) \int_{0}^{\infty} e^{-i\omega x} \, dx = \frac{1}{\sigma + i\omega}
\]

Since \( \sigma \to 0 \) we obtain the “Fourier image” \( 1/(i\omega) \) of a unit step function, which the Fourier transform refused to evaluate.
This way we can obtain the Laplace images of other “problematic” functions, the Fourier images of which do not converge.

The introduction of the small “asymmetry” into the Fourier transform enables obtaining the Laplace transform, which allows transforming even more functions than the Fourier transform does.

5. Principle 5: Merging and combining and the factorization of sets

This principle says: “bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations.”[1]

Suppose we have a class of thirty pupils. In the language of sets, we say that we have a 30-element set. Every element of this set – pupil; has certain characteristics, which allows us to compare it with other elements. Let us take a height of a pupil. Having average height we can group together tall pupils and short pupils. Thus, we say that we have factorized the set of pupils according to their height. The resulting factor set will consist of two elements – tall and short pupils. From the point of view of factorization, all tall pupils are equivalent. The same holds for the group of short pupils.

This way we can factorize the set of integer numbers \( \mathbb{Z} \) according to divisibility by 2. The resulting factor set will contain of two elements – even and odd numbers. All even numbers are grouped together and are equivalent the same holds for all odd numbers that are also grouped together. The factor elements are written into the square brackets \([ \ldots \] \]. For all even numbers we can write equivalence: \( \ldots = [-2]=0=[2]=4=\ldots \) the same holds for all odd numbers \( \ldots = [-1]=1=[3]=5=\ldots \). The sign \( \ldots \) represents the equivalents of elements.

6. Principle 6: Universality and generalization

Make a part or object perform multiple functions; eliminate the need for other parts.”[1] sounds the universality principle.

As an example, let us consider the trigonometric substitution that serves as a guide to calculation of any integral in the form of

\[
\int R(\sin x, \cos x) \, dx
\]

Where \( R \) is some rational function with the \( \sin x \) and \( \cos x \) as variables. Making the substitution:

\[
\tan \frac{x}{2} = t
\]

We obtain the following id entities

\[
\sin x = \frac{2t}{1 + t^2} \quad \cos x = \frac{1 - t^2}{1 + t^2}
\]

As a result, the original integral will transform to the form of rational function that is easier to evaluate:

\[
\int R(t) \, dt
\]

7. Principle 7: Nested doll

This principle says that all the child objects are hidden inside the parent object. Literally; “Place one object inside another; place each object, in turn, inside the other. Make one part pass through a cavity in the other.”[1] The simplest numerical example of this principle represent factorials:

\[7! = 7 \cdot 6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 = 5040\]

Another good example of the use of Nested doll principle are self-similar fractals. These fractals are replicating exactly the same pattern at every scale. This recursive self-similarity can be illustrated by Koch snowflake.

8. Principle 10: Preliminary action

The principle says, “Perform, before it is needed, the required change of an object (either fully or partially). Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.”[1]

A good example for preliminary action in mathematics is the method of undetermined coefficients. This method allows to solve the non-homogeneous ordinary equations by ‘guessing’ the form of the particular solution. Let us consider following equation:

\[
\frac{dy}{dx} - y = e^x
\]

The homogenous solution to this equation is:

\[y_h = c_1 e^x\]

We see that that the homogenous solution is “resonating” with the particular part, therefore our guess is of the form:

\[y_p = A x e^x\]

Substituting back to the initial equation and determining the coefficient \( A \):

\[
\frac{d}{dx}(A x e^x) = A x e^x + e^x
\]

\[A x e^x + A e^x = A x e^x + e^x\]

\[A = 1\]

Therefore the general solution to this differential equation is:
\[ y = y_n + y_p = c_1 e^x + x e^x \]

Guessing the result in advance and estimating the missing coefficients is often easier than doing the separation of variables or Laplace transforms.

9. Principle 13: The other way round

"Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it). Make movable parts (or the external environment) fixed, and fixed parts movable). Turn the object (or process) ‘upside down’."\(^{[1]}\) advises principle.

The Other way round principle is equivalent to mathematical proof by contradiction. This indirect proof is based on fact that if we manage to prove the opposite proposition being false, thus, we showed that the initial proposition is true.

A very interesting example is proving that the eigenvalues of real symmetric matrix are all real.

Firstly, let us suppose that the opposite is true: i.e. let \( \lambda \in C \) be a complex eigenvalue of a real symmetric matrix \( A \in \mathbb{R}^{n \times n} \), \( A^T = A \) and \( u \in C^n \) be a corresponding eigenvector \( Au = \lambda u \).

Taking complex conjugates of both sides, we obtain:

\[ A^* u^* = \lambda^* u^* , \text{ since } A \text{ is real, } A^* u^* = \lambda^* u^* \]

Now let us transpose the obtained equation:

\[ (A u^*)^T = (\lambda u^*)^T \]
\[ (u^*)^T A^T = (u^* )^T \lambda^* \]

Since \( A \) is a real symmetric matrix, we can multiply both sides of equation by vector \( u \) and get:

\[ (u^*)^T A u = (u^* )^T \lambda^* u \]

Substituting \( Au = \lambda u \) and rearranging we obtain:

\[ \lambda (u^* )^T u = \lambda^* (u^* )^T u \]

Thus:

\[ (\lambda - \lambda^*) (u^* )^T u = 0 \]

Since \( u \) is a non-zero eigenvector and

\[ (u^* )^T u = \sum_{i=1}^{n} u_i^* u_i > 0 \]

Hence, \( \lambda = \lambda^* \), i.e. any \( \lambda \) of a symmetric real matrix is a real eigenvalue.

Another famous example to the proof by contradiction is the proof that the \( \sqrt{2} \) is an irrational number – see [5].

10. Principle 16: Partial or excessive action

The principle says, "If 100 percent of an object is hard to achieve using a given solution method then, by using ‘slightly less’ or ‘slightly more’ of the same method, the problem may be considerably easier to solve."\(^{[1]}\)

The excessive solutions are applied in a squeeze theorem, which says that if functions \( f, g \) and \( h \) satisfy the inequality:

\[ g(x) \leq f(x) \leq h(x) \]

And

\[ \lim_{x \to A} g(x) = L = \lim_{x \to A} h(x) \]

Then

\[ \lim_{x \to A} f(x) = L \]

The squeeze theorem is applied for the limits where the usual algebraic methods are ineffective. Please, see [4], for more examples on the application of the squeeze theorem.

We can use Newton’s binomial theorem to estimate Euler’s number \( e = 2.718281… \) We will start form the well-known identity:

\[ e^1 = \lim_{n \to \infty} \left( 1 + \frac{1}{n} \right)^n \]

The binomial on the right hand side can be expanded with the help of Newton’s binomial theorem:

\[ \left( 1 + \frac{1}{n} \right)^n = \sum_{k=0}^{n} \binom{n}{k} \left( \frac{1}{n} \right)^k \]

\[ = \sum_{k=0}^{n} \frac{n!}{k! (n-k)!} \left( \frac{1}{n} \right)^k \]

\[ = \sum_{k=0}^{n} \frac{1}{k! (n-1)!} \ldots (n-k)! \]

\[ = \sum_{k=0}^{n} \frac{1}{k! n^k (n-1)!} \]

\[ = \sum_{k=0}^{n} \frac{1}{k! n^k (n-1)!} \]

If \( n \) goes to infinity, the sum on the right hand side can be written as:

\[ \sum_{k=0}^{\infty} \frac{1}{k!} = \frac{1}{0!} + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \ldots \]

These first five terms will give the estimate \( e \approx 2.70833… \) In this case we are satisfied with approximate (partial) solution.

Another good example for partial solution is the approximation of a function in a given point by Taylor series. The last but not least, the optimization problems and some control problems are solved by finding a solution to either a little stronger problem or to a problem that is a little less strong than the given one.
11. Principle 14: Curvature

“Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures. Use rollers, balls, spirals, domes. Go from linear to rotary motion, use centrifugal forces.”[1] advises principle.

A very good example is a coordinate transformation from Cartesian coordinates to polar coordinates during the computation of double integrals. As an example let us consider the following integral:

$$\int_{-3}^{3} \int_{0}^{\sqrt{9-x^2}} \sin(x^2 + y^2) \, dy \, dx$$

The picture of the domain of this integral is following:

![Fig. 4 Transformation of coordinates](image)

The transformation of coordinates from Cartesian to polar is done via substitution:

$$x = r \cos \theta, \quad y = r \sin \theta$$

The Jacobian determinant for the polar coordinates transformation is:

$$\det(J(r, \theta)) = \begin{vmatrix} \frac{\partial x}{\partial r} & \frac{\partial x}{\partial \theta} \\ \frac{\partial y}{\partial r} & \frac{\partial y}{\partial \theta} \end{vmatrix} = \begin{vmatrix} \cos \theta & -r \sin \theta \\ \sin \theta & r \cos \theta \end{vmatrix} = r \cos^2 \theta + r \sin^2 \theta = r$$

The integral with polar coordinates is:

$$\int_{0}^{\pi} \int_{0}^{3} \sin(r^2) \cdot r \, dr \, d\theta$$

The evaluation of this integral is done in two steps. At first, we calculate the inner integral then the outer one.

$$\int_{0}^{3} \sin(r^2) \cdot r \, dr \overset{\text{substitution}}{=} \frac{1}{2} \int_{0}^{9} \sin u \, du = \frac{1}{2} \int_{0}^{9} (1 - \cos 9) = \sin^2 \left(\frac{9}{2}\right)$$

In the last step, we used trigonometric identity

$$\sin^2 \varphi = \frac{1}{2} (1 - \cos 2\varphi)$$

Now we are ready to calculate the remaining outer integral:

$$\int_{0}^{\pi} \sin^2 \left(\frac{9}{2}\right) \, d\theta = \pi \sin^2 \left(\frac{9}{2}\right)$$

This procedure shows how to implement the curvature principle in transformation of the integral domain into polar coordinates.

12. Principle 17: Another dimension

“The principle suggests, “To move an object in two- or three-dimensional space. Use a multi-story arrangement of objects instead of a single-story arrangement. Tilt or re-orient the object, lay it on its side. Use ‘another side’ of a given area.”[1]

The application of the principle of another dimension is usually applied when the problem in a given set of numbers is unsolvable. For example, let us consider a quadratic equation that is unsolvable in the set of real numbers:

$$x^2 + 4x + 5 = 0$$

The square root function is not defined for the negative argument. Therefore, the set of complex numbers with its special rules was invented. In the set of complex numbers the solution of this equation is:

$$x_1 = -2 + 2i \quad \text{and} \quad x_2 = -2 - 2i$$

Where $i^2 = -1$. Due to the Euler’s formula:

$$e^{i\varphi} = \cos \varphi + i \sin \varphi$$

We are able to express rotations in a complex plane. The rotations in a 3D plane can be represented by normalized quaternions. Quaternions are four-dimensional vectors that are represented by real scalar part and vector complex part. Quaternions have found their way in robotics, computer graphics and space applications.

There is another young, but yet very interesting branch of mathematics – fuzzy logic. Using fuzzy logic, we are able to solve tasks that are not solvable by the classical logic. For example, if the drop of petrol does not cost anything, the same as two drops of petrol are for free, than how come that the full tank costs us money? If we follow classic logic induction principle than the full tank should be for free. Fuzzy logic allows solving such problems; moreover, it becomes popular in the feedback control systems.


Principle suggests, “Introduce feedback (referring back, cross-checking) to improve a process or action. If feedback is already used, change its magnitude or influence.”[1]
In a control theory, there is a chapter dedicated to a feedback theory. A, B, C and D matrices are representing the feedback system that is shown on the next figure:

![State space model of a feedback system](image)

The so-called state-space model of the system is described by the following system of equations:

\[ X(s) = AX(s) + BU(s) \]

\[ Y(s) = CX(s) + DU(s) \]

Where \( X(s), U(s) \) and \( Y(s) \) are representing the Laplace images of the states, inputs and outputs.

Besides the evident application of a feedback in a control theory there is also a numerical approximation method to solve ordinary differential equations called Runge-Kutta fourth order method (also known as RK4 method). As soon as an initial value problem is explicitly specified:

\[ y = f(t, y) \quad \text{and} \quad y(t_0) = y_0 \]

For the step size \( h > 0 \) the next step is calculated from

\[ y_{n+1} = y_n + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \]

Where \( n = 0, 1, 2, 3, \ldots \) and \( y_{n+1} \) is the RK4 approximation of \( y(t_{n+1}) \) where \( t_{n+1} = t_n + h \) and

\[ k_1 = f(t_n, y_n) \]

\[ k_2 = f(t_n + \frac{h}{2}, y_n + \frac{h}{2}k_1) \]

\[ k_3 = f(t_n + \frac{h}{2}, y_n + \frac{h}{2}k_2) \]

\[ k_4 = f(t_n + h, y_n + hk_3) \]

We see that every next step is approximated from the previous one by some numerical computations.

The discrete system for RK4 is shown on the next figure:

![The model of Runge-Kutta fourth order approximation method](image)

We see that the system is a feedback system with weighted average slope feedback.


“Use an intermediary carrier article or intermediary process. Merge one object temporarily with another (which can be easily removed).”[1] advises principle.

In mathematics, we often use letters as intermediary for unknowns. Very popular letters representing unknowns are \( x, y \) and \( z \). It is often a good habit to find a good substitution to simplify the calculation. Here the intermediary is represented by substitutions in indefinite integrals.

\[ \int f(g(x))g'(x) \, dx \]

Substituting \( u = g(x) \). Let us consider the following integral:

\[ \int x \sin(2x^2) \, dx = \frac{1}{4} \int \sin u \, du = -\frac{1}{4} \cos u + c = -\frac{1}{4} \cos 2x^2 + c \]

The integral substitution is usually not the only substitution example. We usually take substitutions when the rewriting the already evaluated parts is tedious and might cause mistakes.

15. Principle 26: Copying

Principle says, “Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies. Replace an object, or process with optical copies. If visible optical copies are already used, move to infrared or ultraviolet copies.”[1]

The copying in mathematics is usually connected with transformations. In case of linear transformations such as Laplace, Fourier and Z transformations we are talking about homomorphisms. The main idea of these transformations is to create an image of an object in the different domain, the solve the image problem with the ease of that specific domain provides us and at the end to find the solution of an object using an inverse transformation. Let us see the procedure of Laplace transform:
16. Conclusion

The purpose of this article is to bring simple and clear examples that will provide short guide in application of inventive principles from the Theory of Inventive Problem Solving (TRIZ).

In this work, we used problems with known solutions and retrospectively fitted the TRIZ principle. Although to solve the technical contradictions there exists the table that advices which principle to use, in terms of mathematical problems, no such table has been developed yet. The elaboration of the table can be considered as a dignified goal for a person with firm mathematical background.

Nowadays, there are still unsolved problems that are waiting for their solution – mathematicians that are aware of TRIZ might use any of 40 inventive principles to solve their problem. We would like to encourage searching for the TRIZ in the internet via links in references – see [1],[7].

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References

Approach to solve the EAF breakage in FeNi production process

Younghan Jeonga, Jaemin Leeb, Taeyoung Leeb

*POSCO Group University, 120 Jigok-ro, NamGu, Pohang City, 790-834, Korea
bSNNC, 2148-139, Jecheol-ro, Gwangyang City, 545-826, Korea

* Corresponding author. Tel.: +82-010-7761-9097; fax: +82-054-221-5040. E-mail address: joyyounghan@poscohrd.com

Abstract

This project shows an application of TRIZ process and tools to improve ferronickel (FeNi) productivity and enhance profitability through an improvement in electric arc furnace (EAF) utilization. Electric arc furnace, a process of producing FeNi molten iron, uses electrodes to supply electricity and smelt Ni ore. There is a problem of EAF electrodes breakage. The electrodes breakage usually occurs after electric arc furnace undergoes repair process. The breakage stems from defects in the electrodes which are cooled during the repair. A prior solution to this problem is to install a heating pad, but it is a difficult task because of complexity of the pad. Even if it is installed there is no effect. To prevent electrodes breakage, this project employed the TRIZ process and TRIZ tools. The TRIZ analysis tools were used to analyze the problem and to select the core problems. Using the substance and field model, solution directions were set. Solution directions were set improving the supportability of the electrodes and suppressing the growth of defects. Using the TRIZ ideation tools, several ideas were generated. After new ideas generated by TRIZ were applied, electrodes breakage problem was completely resolved.

Keywords: TRIZ process, Substance and field model, Hypothesis, Electric arc furnace, Ferronickel, Electrodes breakage

1. Introduction

There are many tools to help the engineers and researchers to develop innovative products in the technical field. Among them, TRIZ, which has been developed by Altshuller, is a very useful tool to create fresh and innovative idea for the engineers and researchers in the technical field. Recently in Korea, many companies have utilized TRIZ, and many successful applications of TRIZ have also been reported [1, 2]. In this paper, it is shown how TRIZ and TRIZ tools for creating innovative ideas have been useful for solving the problems and enhancing the productivity and profitability quality in the ferronickel industry.

2. Project background and Problem Situation

2.1. Project background

An electric furnace is a process of producing FeNi molten iron and slag through smelting and reduction of ore that went through preliminary reduction process. After electric arc furnace was repaired in 2012, EAF electrodes breakage has been on the rise. The number of electrodes breakage is shown in Fig.1.
Whenever electrodes break down, EAF utilization declines about 4% and FeNi production losses are more than 280 ton. The EAF electrodes breakage has to be improved and the EAF utilization has to be increased for productivity and profitability.

2.2. Problem Situation

There are three electrodes on the roof of the furnace. The type of the electrodes is Soderberg type. The Soderberg electrodes are produced using steel casings welded together to form a cylinder 3 stories high above each of the furnace electrodes. At the open top of the steel casings, solid carbon blocks are added. As the electrodes are consumed in the process below, the solid blocks descend towards the furnace and are heated. The blocks first melt inside the casing, and then as they pass through a power input section, they become hot enough to bake and become solid. As the electrode exits the power input section, the carbon is now a solid round electrode, and the spent steel casing melts into the electric furnace. The electric arc furnace and Soderberg electrode are shown in Fig.2.

Electric arc furnace electrodes break down and time of the occurrence is around 9~10 hours later after EAF electrodes are powered by electricity. The breakage stems from defects in the electrodes which are cooled during the repair. A prior solution to this problem is to install a heating pad. The pad can supply heat energy on the softening zone during repairing the EAF and to keep the heat energy in the EAF and to suppress growth of defects on the softening zone. But it is a difficult task because of complexity of the pad. Even if it is installed there is no effect.

3. Solving the problem by TRIZ

3.1. TRIZ Process

To prevent electrodes breakage, this project employed the TRIZ process and TRIZ tools. The process which is used in this project is shown in Fig.3.

Function Analysis is used to analyze the problem situation and to select core problem for solving it. Su-F model is set to model the problem and define the hypothesis for solution. This problem has a lot of constraints and it is important to find some kinds of resources which are made use of. To generate some ideas for removing the electrodes breakage, TRIZ ideation tools such as 76-standard solutions, 40 inventive principles, ARIZ concepts and evolution patterns are used.

3.2. Operation and function analysis

Solid carbon blocks (briquettes) changing mechanism in the Soderberg electrode process. The mechanism is below.

1. Briquettes begin to change softly about 25°C~100°C.
2. Happens to cohere between briquettes about 200°C~300°C.
3. Briquettes are changing from solid state to liquid state about 350°C~450°C. The liquid briquette are called softening zone. When the softening zone is cooled suddenly, defects
are made and heating on the softening zone some cracks are generated in it.
④ There are some binders in the solid carbon blocks for binding briquettes. Binders are evaporated and liquid briquettes begin to be solid about 600°C~700°C.
⑤ Briquettes have been changed a solid lump of carbon about over 900°C.

To analyze the functions of the problem situation and the system we make use of function analysis. We define core problems. One of the core problems is that solid round electrode pulls solid carbon graphite with cracks in case of power on after fixing EAF. The other is that softening zone is so cooled suddenly by cool air in case of power off for fixing EAF. Function analysis and core problem definition are shown in Fig.4.

3. Hypotheses for solving directions and Ideation

Su-F model is used to model the core problems. These core problems have harmful functions and harmful interactions have to be cut. Four hypotheses are formulated to solve the core problems.

H1: to improve the supportability of electrode
H2: to block the gravity
H3: to reduce the weight of solid electrode
H4: to suppress the growth of cracks

First of all, we try to find some resources to satisfy hypotheses. The candidates are called x-elements. For example, Hypothesis 1 (H1) is to improve the supportability of electrodes. X-elements can be steel casing, fin and fin windows etc. We can define the ideal final result, IFR, of H1 that without complication of the system and without harmful side effects, during power on, inside electrode in the EAF, casing improves the supportability of electrodes. Using x-elements and TRIZ ideation tools such as 40 inventive principles and evolution patterns, a lot of ideas for satisfying the H1 are generated. How to define hypothesis is shown in Fig.5.

3.4. Idea simulation and implement

We generated many ideas for solving the problem. But some ideas can’t be applied because there are a lot of constraints in the process. Ideas are screened and workable ideas are made progressed and simulated for reliability. Simulation of strong stress area distribution is shown in Fig.6. After applying the new ideas strong stress area becomes more narrow than before.

3.5. Results

Several ideas are applied to improve the EAF electrodes breakage and electrode breakage is completely improved. Result of applying new ideas to solve the electrode breakage problem is shown in Fig.7.
The TRIZ ideation tools and TRIZ process are so effective and powerful for solving the industry problems.

References

TRIZ methodological consideration for the impact banding improvements

Sooyong Kim a*, Sungdae Kim a, Sangbum Woo a

aDriving Lab., Printing Business, Samsung Electronics Co., Ltd.
129, Samsung-ro, Yeongtong-gu, Suwon-si, Gyeonggi-do 443-742, Korea

* Corresponding author. Tel.: +82-10-4140-7907; fax: +82-31-200-0387. E-mail address: sy001.kim@samsung.com

Abstract

In this paper, as a way to improve image quality of a digital image forming device, TRIZ methodology is applied to minimize the fluctuation in rotation velocity of photoconductor drum. A digital image forming device normally uses laser light to create a latent image on a photoconductor drum which requires the drum to rotate at a constant speed. However, the rotation speed of the photoconductor drum is interfered by media like paper and other mechanic parts. In order to get a high quality image, constant-high speed rotation should be implemented, but when a media is being transferred at a fast pace in a given space for a quick print job, vibration and speed fluctuation occur. Such technical contradictions are expressed as physical contradictions, and their solutions are provided by using the principle of time separation and standard solution.

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Keywords: Banding, Line Banding, Jitter, Problem Analysis

1. Introduction

Pictures and letters printed by a laser printer or a copier are made of dots and lines of black or colors. In general, a laser printer or a copier, which is a representative device for expressing digital image information on a media, goes through a five basic process (charging, exposure, development, transfer and fusing) as shown in the Fig.1. During the process, when the original image is not expressed in dots and lines of ideal size and density various defects occur. Among various image defects, banding refers to lines, as in Fig. 2, that occur due to the density difference of white and black in vertical direction to the paper passing through the printer.[1] Depending on the phase of the printing process, banding occurs when 1) there is a velocity fluctuation in the driving mechanism to rotate the OPC when a digital image is forming, 2) various rollers have different speed in the development phase, in which toner is applied to the latent image on OPC, 3) there is a variation in speed of media when the image developed on OPC is transferred to belt or paper. Among the three cases, the first type of banding is the most frequent. Banding can be also classified into periodic or non-periodic. In addition, banding that occurs in short cycles in a page is called jitter, and one that occurs 1~2 times in a page non-periodically is called line banding. Jitter is a type of banding that occurs repetitively with cycle of less than 5mm. It happens when the interval of dots is irregular due to the fluctuation of OPC’s rotational speed, which should be

Fig. 1 Schematic diagram of electro photographic (EP) process
consistent. A lot of advances were made on the defect with the modelling by Chen et al, and many studies were conducted on evaluation method and how to improve it. [2-5]

In this study, banding caused by inconsistent OPC drum speed from non-periodic disturbance is defined as line banding, and a number of methodologies and solutions are proposed to eliminate it.

2. Case Study Description and Methodology

2.1. System and problem definition

System Analysis

In the printing process of a laser printer or a copier, OPC plays a central role for five electro-photographic process (charging, exposure, develop, transfer and fusing). The OPC drum normally rotates at a constant speed by the driving motor, and the structure of an OPC drum is similar to Fig 3. From the motor, the driving source, to OPC that rotates at a constant speed is defined as a system where the problem occurs. All the factors that contribute to speed fluctuation, which is the cause of line banding, are classified and each of their impact is reviewed. Table 1 shows the result of analyzing the defined system with Multi-Screen Thinking method. With this system analysis, it is verified that OPC’s uniform motion is interfered by an impact on OPC from paper as well as small and momentary speed changes that occur as paper goes through the OPC and transfer roller, which is described in Fig. 4.

2.2. Root Cause Analysis

In order to more deeply analyze the cause of OPC drum’s rotational speed fluctuation, Root Cause Analysis (RCA) was conducted and derived Core Problems (CPs). Fig. 5 is the RCA on the correlation between the changes that occur when a paper goes through OPC and transfer roller nip and banding.
Through the RCA analysis, two contradictory problems and one root cause are derived. A motor, the driving source, is made of components that are connected in contact to deliver rotation from the motor, which can be described as Formula 1.

There is a contradiction because the torsional rigidity of the overall system should be high for speed consistency, but considering actual production cost and production applicability, it should be low. CP2 is derived by analyzing speed imbalance of a paper when it enters OPC NIP. The contradiction here is that in order to print quickly, the media should move fast, but in order to eliminate the impact from speed fluctuation, the media should move slow. CP3 is that contact force between the OPC drum and the transfer roller should be strong for high transfer efficiency, while it should be weak for uniform image quality. Table 2 summarizes three CPs derived from the above analysis. CP1 and CP2 are contradictory problems. However, because CP3 is a fundamental problem that cannot be changed for printing, it is excluded from this study’s scope for finding solutions.

### 3. Result and Discussion

This chapter describes the TRIZ methodology applied to solve the CPs defined in chapter 2 and its result.

#### 3.1. Approach for solving the CP1 and the solutions

From torsional rigidity of motor, the driving source, to OPC, where an image is formed, is reviewed to solve CP1, which is defined by using the RCA. After considering many methods, two solutions are eventually applied to increase the rigidity.

#### 3.1.1. Construction of references

First, Fig. 6 shows our analysis on the functions of the system. As shown in the diagram, we came up with the first solution by analyzing each component’s function and undesirable flows of functions to increase the overall stiffness by reducing the number of stages that connect the system. First, through a function analysis of each component, we found that maintaining the functionality of the system is possible even when the number of connection steps of components is reduced. We used the trimming method to trim the components that can be eliminated, while maintaining the overall system functionality. Fig. 7 shows this model and it is also briefly expressed in Formula 1. We confirmed the result by minimizing the mechanical connection stages (Steps) using the following equation 1, and CAE.

**Table 2 Core Problems**

<table>
<thead>
<tr>
<th>NO</th>
<th>Core Problems</th>
<th>Beneficial Effect[+]</th>
<th>Adverse Effect[-]</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP1</td>
<td>Torsional Rigidity of rotated components is Low(→)</td>
<td>Compactness of the Overall design is possible</td>
<td>Internal heat Dissipation is low</td>
<td>1</td>
</tr>
<tr>
<td>CP2</td>
<td>Speed of the paper is fast(→)</td>
<td>Printing performance is good</td>
<td>Static Property of rotated members is low</td>
<td>2</td>
</tr>
<tr>
<td>CP3</td>
<td>OPC contact with Transfer member(→)</td>
<td>Contact is necessary for Image transfer</td>
<td>Load variation of OPC is high</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 3 Test Result of CAE**

<table>
<thead>
<tr>
<th>Drive shaft</th>
<th>Coupler</th>
<th>OPC shaft</th>
<th>OPC holder</th>
<th>Total torsional moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>C project</td>
<td>1,012,000</td>
<td>105,000</td>
<td>72,000</td>
<td>100,000</td>
</tr>
<tr>
<td>P project</td>
<td>667,000</td>
<td>160,000</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
\[
\frac{1}{k_{\text{total}}} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \cdots
\]  

Fig. 8 is the actual result with eliminated components and improved stiffness, and it was applied to the final design after being verified through CAE and other experiments. Table 3 shows the change of torsional stiffness in CAE results, before and after application. After removing the number of connection steps by using the trimming method, we could confirm improved stiffness.

### 3.1.2. Su-Field model and Inventive Standard Solution

After applying the method to increase stiffness by reducing the number of stages of moving parts, there was room to improve banding to enhance image quality, so we reviewed more methods. From this point on, the driving system with the minimum number of connection steps (as in 3.1.1) was used. The second method applied to increase stiffness was the Inventive Standard Solution, and for this we created the Su-Field Model. However, there was a contradiction. Driving force is transmitted through the shaft and gear from the motor, and to send out fine vibrations and prevent jitters, the plastic gear needs to be soft. But on the other hand, in terms of torsional stiffness, it needs to be hard.

\[
\frac{1}{k_{\text{total}}} = \frac{1}{k_{\text{flange}}} + \frac{1}{k_{\text{gear}}} + \frac{1}{k_{\text{shaft}}}
\]

To solve this contradicting problem, we reviewed various Su-Field Models and as a result, 1-1-3, shown in Fig. 9 was applied.

The final solution to increase torsional stiffness was adding S3, an intermediate medium metal holder, between the mold gear and shaft. This method was used to enhance the stiffness of S2 (gear + shaft) that transmits the torsional stiffness. Fig. 10 is one example of various modeling samples which includes an intermediate medium holder and uses Group1 to calculate torsional stiffness. In Fig. 11 you can see the shape of the final optimized model applied to the product.

### 3.2. Approach to solve CP2

When the previously mentioned contradiction becomes severe in the course of solving the CP2 problem, a technical contradiction happens because the speed of the paper or media needs to be fast but at the same time, to prevent shocks, the speed must not be fast (Fig. 12).

Separating the time in which the problem occurs was a solution to the contradiction, as shown in Fig. 13. We came up with a way of controlling paper speed by separating speed in OT1 and OT2. In OT1, where the typical printing process happens, we increased the speed to meet the speed of the system we designed and in OT2, where banding happens because of shocks, we slowed the paper speed which caused shocks.

The final solution for CP2 is the algorithm shown in Fig. 14, which slows the speed just at the moment paper enters the OPC. A new patent was filed for separating OT1, OT2
according to the velocity(x). At hindsight, the solution may seem somewhat simple, however, the result is meaningful in the sense that we faithfully approached the TRIZ method to solve the problem.

Fig. 15 shows OPC speed with improved banding when the final controlling method is applied to thick paper and Fig.16 shows resolutions printed on paper, verifying the test result.

4. Conclusion

In this study, we tried to use the TRIZ methodology to address the banding problem which was caused by media shocks. After defining the problem, three solutions were derived under subdivided goals. We could improve the problem of the overall system by applying all three methods. At hindsight, the solutions may seem rather simple. However, when we were defining the problem, it was not easy to suggest these solutions. The TRIZ method was used as early as in the defining step and in the course of logically explaining the solution and verifying through experiments and analytical ways, we reached the final solution. Therefore, this study is meaningful because of the faithful approach to the TRIZ methodology, which eventually led us to find a solution to the difficult problem.

References


Design Thinking Process with Simplified TRIZ

Kyeongwon, LEE*

Department of Mechanical Design Engineering, Korea Polytechnic University, Siheung City, Kyonggi-Do, 429-793, Korea

* Corresponding author. Tel.: +82-31-8041-0426; fax: +82-31-8041-0439. E-mail address: lkw@kpu.ac.kr

Abstract

TRIZ is Russian acronym of “Theory of Inventive Problem Solving”. So there are so many problem solving tools than tools for human-centered problem finding. It is very important to find and define the human-centered problem and project in highly competitive economics these days because of faster changes of customer’s needs. TRIZ that has used mostly in mechanical and manufacturing fields gives just some conceptual ideas and sometimes innovative, but vague ideas so that TRIZ users do not confirm that the ideas are working well or not in short time. The Design Thinking process can compensate such the weakness of TRIZ well.

The “Empathize” and “Define” step of the Design Thinking process are effective steps for compensating TRIZ for finding the human-centered problem as “Pre-TRIZ”. The fast and cheap “Prototype” step of the Design Thinking process is serial step for communicating the TRIZ ideas better with others and then, effective implementation of conceptual ideas by TRIZ as “Post-TRIZ”. Vice versa, the Design Thinking process has big shortage on generating innovative ideas in the “Ideate” step because it depends on group brainstorming method by all participants. Therefore TRIZ and Design Thinking Process can compensate each other.

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Keywords: Design Thinking Process; Weakness of TRIZ; Problem Finding; Rapid prototyping

1. Motivation

In modern society “human-centered problem finding” for business opportunity is more important than problem solving because of faster changes of customer’s needs.

TRIZ is Russian acronym of “Theory of Inventive Problem Solving” [1, 2]. That is, it is one method and process for just problem solving especially for problems with contradictions. TRIZ has so many problem solving tools than tools for human-centered

Before “Problem Solving”, the finding human-centered problem is important. What is human-centered problem? The human-centered problem in Design thinking is the problem that gives some values to related customers and users. And it has to inspire solvers and innovators that it gives challenging problem to them, too in one invited talk on introduction to Design thinking of d.school at Stanford University [3].

The “Empathize” and “Define” steps of Design Thinking process are effective for compensating TRIZ for the human-centered problem finding well as “Pre-TRIZ” stage.

In addition, TRIZ is one method and process on just conceptual design stage. Especially it has strong points to resolving contractions. But it is difficult for general persons to learn and then, apply to solve their own problems

It gives just conceptual ideas than more concrete ideas. Hence the TRIZ users may not conformed whether the conceptual ideas by TRIZ can be implemented by technical and business aspects in the field well or not later. The fast and cheap “Prototype” step of Design thinking process can compensate such a weakness of TRIZ as “Post-TRIZ” stage to show and communicate the TRIZ ideas with others better.

Vice versa, the Design Thinking process has big shortage on generating much better and innovative ideas in the “Ideate” stage because it depends on group brainstorming method or simple creativity-related methods such as MINDMAP or at best, SCAMPER method by all participants. If the users of
Design Thinking wants to solve problem much better, especially in cases that the ideas by the group brainstorming of design thinking has such a contradiction, conflict and dilemma, many methods to resolve the contradiction in TRIZ may give much better and innovative ideas to resolve them.

In this paper, author explains one simplified and light version of TRIZ process, so-called the “Quick TRIZ process” for the users of Design Thinking [4]. Many users of Design Thinking and general persons have complained that conventional TRIZ is so complex and heavy for them to learn and use it and useful only for almost manufacturing problems. A real case study on getting much better ideas for next generation of the self-camera stick of smart-phone in several hours is explained by using the “Quick TRIZ Process” as one simplified TRIZ version on the “Ideate” step of Design Thinking process.

2. Design Thinking Process at d.school, Stanford Univ.

The Design Thinking process first defines human-centered problem carefully and then, implements the solutions, always with the needs of the user demographic at the core of concept development. This process focuses on need finding, understanding, creating, thinking, and doing. At the core of this process is a bias towards action and creation: by creating and testing something, you can continue to learn and improve upon your initial ideas [5].

The Design Thinking process consists of these 5 steps:

1) “Empathize” step: Work to fully understand the experience of the user for whom you are designing. Do this through observation, interaction, and immersing yourself in their experiences

2) “DEFINE’ step: Process and synthesize the findings from your empathy work in order to form a user point of view that you will address with your design.

3) “IDEATE” step: Explore a wide variety of possible solutions through generating a large quantity of diverse possible solutions, allowing you to step beyond the obvious and explore a range of ideas. In many cases, the methods to generate ideas almost depend on brainstorming of multidisciplinary team.

4) “PROTOTYPE” step: Transform your ideas into a physical form rapid and cheaply so that you can experience and interact with them and, in the process, learn and develop more empathy.

5) “TEST” step: Try out high-resolution products and use observations and feedback to refine prototypes, learn more about the user, and refine your original point of view.

3. Compensation TRIZ by Design Thinking Process

TRIZ has no steps to include human-oriented latent and changing needs. The human-centered “Empathize” step of Design Thinking process uses careful observation of user’s vivid actions, user’s intensive interview and solver’s experience. The step knows and defines problem solvers the human-centered problem correctly that user and customer have latently. It is much effective steps for compensating TRIZ for finding human-centered problem well as “Pre-TRIZ” stage.

For nice and more implementations from ideas by TRIZ to practical innovation and commercialized products or service, the human-centered problem definition for customers can give the innovator and problem solver the inspiring to challenge.

In addition, TRIZ is one method and process for just conceptual design stage. So it gives just conceptual ideas than more concrete ideas. Hence TRIZ users may not conformed whether the conceptual ideas by TRIZ can be implemented by technical and business aspects in the field well or not. They need some additional steps to explain the TRIZ ideas to others.

For instance, some TRIZ promotion team at big companies such as SAMSUNG in Korea have matched and linked both idea generators by using TRIZ and different domain experts with computer aided simulation and analysis, making mock-up, simple experiment and patent database. The fast and cheap “Prototype” step of Design thinking process between idea generation stage of TRIZ and more expensive working prototype can compensate TRIZ as “Post-TRIZ” stage. For more implementation better and reduce the time for R & D fast, cheap and low-level prototyping is very important for TRIZ users who may not give strong confidence on their conceptual ideas. Through the cheap and fast “Rapid prototyping” they can know the possibility at early step on generating other new problems before it is applied to high-level and more expensive prototype or product/ service.

4. New ideas of next self-camera stick of smart phone

The self-camera stick of smart phone is most popular product in 2014 in the world, especially in Korea. Author as a professor at Department of mechanical design engineering, Korea polytechnic University had asked 3rd grade, junior 80 students with 4 students per team to apply the Design Thinking
process first and then, apply the “Quick TRIZ” process in the “Ideate” step in fall semester, 2014.

In the “Empathize” step of Design Thinking process, he had asked to list and write down 5 complaints or things to be improved for students after using the sticks, careful observation and interviews of the stick users as following sheet by one team with 4 students as shown in Fig. 2.

![Fig.2. Empathize step of self-camera stick in Design Thinking process](Image)

On all complaints as the right problem defined, they had generated many ideas to remove the complaints by group brainstorming depending on their own experience, intuition and knowledge. They had shown incremental and improved ideas mostly such as using some light materials against the heavy stick as the first “heavy” complaint of problem. Sometimes they had not generated any useful ideas at all against other complaint. If there is no idea to remove the complaint, they may search for information and ideas by internet.

![Case study] Self-camera (Selfish) Stick of Smartphone

(“Ideate” : Idea generation stage)

- idea for more convenient self-camera stick:

1) Too heavy
2) Inconveniences to grasp stick
3) Hard to adjust shooting timing
4) Prolonging holder of stick in pocket
5) Short length of selfie-stick for wide shooting

Complaints (problem Define) => ideas by experience, intuition and brainstorming

Snowballing: Use experience, careful observation, interview

To fill the conflict diagram of self-camera stick in Quick TRIZ process, first describe the purpose of “to shoot wide” in using the self-camera stick into the box B and then, choose one idea, means and method of “length of stick has to be longer” into box the D by group brainstorming of the “Ideate step” of Design Thinking process.

By the way, the longer stick generates new other problem of “much heavier self-camera stick” into box C.

Solvers want to satisfy two contradictive purposes in the box B and the box C of removing the new other problem as shown in the Fig. 4.

![Fig.3. “Ideate step” of self-camera stick in Design Thinking process](Image)

![Fig.4. First step for the conflict diagram of Quick TRIZ](Image)

Next solvers intentionally describe the revere idea, means and method of D (−D) into the box D’ to satisfy the
contradictive purpose by removing the new other problem as shown in the Fig. 5.

As common goal, they add the contradictory purposes B and C into the box A.

Thus they can model the right physical contradiction step-by-step from the idea by group brainstorming of the “Ideate” step of Design Thinking process.

That is, to satisfy the purpose A, “to shoot widely for taking picture with more persons by the self-camera stick”, one idea, means and method D is “using longer stick than existing stick”.

To satisfy the contradictory purpose C, “not heavy stick more”, the other idea, means and method D’ is “not using longer stick than existing stick”. In the viewpoint of the contradiction of TRIZ, the physical contradiction of “longer” and “not longer” is modeled systematically and step-by-step as shown in Fig. 5.

First the self-camera stick with blue tooth remote control of smart phone is filled into the box, number 1 as present system, current system.

As past system, the conventional and cheap mechanical self-camera stick may be selected in the Fig. 6.

Serially, they may add all contents as the present sub system of components into the box, number 2 and then, the present super system of environment and the industry into the box, number 3, respectively as shown in Fig. 7.

After that they may add as the past sub system of components into the box, number 5 and then, the present super system of environment and the industry into the box, number 6, respectively step-by-step. The present and past system with their sub system and super system are described into the numbered windows systematically.

In addition, solvers can use the numbered and advanced 9 windows of TRIZ more for generating next new conceptual ideas of next generation self-camera sticks systematically as shown in Fig. 6 [6].

Students could use it in just 6 hours TRIZ education with vacant PPT templates including the simple case for students to follow easily.

For forecasting the next generation of the self-camera stick in future they describe some components and technology considering the trends of components and technology from past through present to the future into the box, number 7.

After that, they describe some trends of industry, social and customers from past through present to the future into the box, number 8, too. All have been prepared for forecasting the future system of the next generation of the self-camera stick.

Finally they may get many ideas of next generation self-camera stick by both applying trends and contents of the box, number 8 and applying some improved or new components and technologies to the “present current system” of the box, number 1 simultaneously.

They had shown more innovative and implementable ideas after group discussion with applying the “Quick TRIZ” process and the numbered 9 windows in short time comparing to just group brainstorming of conventional Design Thinking process as follows;

1. Wide-angle lens attached to front camera of smart phone by “using other cheap resource” for the “long” and “not long” physical contradiction of the stick instead of mechanical antenna type stick
2. Self-camera stick with manually self-electric power generation by combining mechanical and manual energy generation technology in the numbered 9 windows
3. Self-camera stick with climbing auxiliary stick by combining increasing trends of outdoor activities & climbing mountain in the numbered 9 windows

4. Self-camera stick with the self-protection stick for young woman by combining trend of increase of single and young woman who is concerning seriously and blatantly in the numbered 9 windows

5. Small cheap drone (small helicopter) with cheap camera module and wireless communication concept by using other cheap resource in TRIZ with the hype of drone popularity with removing other complaint that users do not want to take pictures of the stick itself with unnatural posture

5. Conclusions

Through same case studies at other Universities such as Soongmyung woman University and Halla University etc., author can have confidence that the “design thinking process including the simplified, “Quick TRIZ” process” is much effective for students, beginners to understand both theory and process and TRIZ easily then, to be trained by both Design Thinking process and TRIZ in short time for just 3 hours with much better results.

Conventional TRIZ has a shortage on finding the human-centered problems well. The “Empathize” step of the Design Thinking process is very effective step for compensating TRIZ for finding the human-centered problem as “Pre-TRIZ”.

The fast and cheap “Prototype” and “Test” stage of the Design Thinking process are serial steps for effective communication with others and then, implementation of conceptual ideas by TRIZ as “Post-TRIZ”.

Of course vice versa, the Design Thinking process has big shortage on generating better ideas in the conventional “Ideate” step because it depends on just group brainstorming method, or simple creativity methods such as MINDMAP or SCAMPER method by all participants.

So TRIZ can compensate it well, too. Therefore the mutual compensation of Design Thinking process and TRIZ is good combination with good harmony on human oriented consumer-use products, that is, Business to Consumer products and service problems for human according to following process as shown fig. 8 including the simplified TRIZ, so-called “Quick TRIZ” process that author have devised several years ago.

Author believes that simplified TRIZ combining Design Thinking process is one future direction of conventional TRIZ for spreading TRIZ to general many persons well in short time.

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Fig.8. Figure on mutual compensation of Design Thinking and TRIZ

References
Abstract

The seeds of failure of many TRIZ projects are sewn before any work actually begins. All because the problem the project team believe they need to solve and the actual problem of the intended customer turn out to be two different things. The real challenge here is that in the majority of instances the customer can’t or won’t reveal, or don’t recognise what their real problem is. That in turn is because the ‘real problem’ relates to the intangible, emotional factors that are present in all of us, and which drive us to say one thing when we actually mean another.

TRIZ was originally built around problems that were fundamentally technical, and therefore very tangible in nature. When there are no human emotions involved, TRIZ will do as good a job as any method available anywhere on the planet. When humans are involved, however, the tangible factors represent only half of the full story. People, J.P.Morgan famously stated, do things for two reasons, a good reason and a real reason. The good reason comes from all of the tangible factors. The real reason – the one that drives actual behaviour – comes from all of the intangibles.

The paper hypothesises that until such times as the TRIZ methodology is expanded to encompass a critical mass of the intangible side of the innovation story, it will continue to be doomed to delivering success on only a small percentage of technical-only problem types. The paper goes on to describe a longstanding programme of research to understand what ‘critical mass’ means in this intangible context, and describes what the author now believe constitutes such a critical mass. In the world of human emotions, as in the world of technical problems, a mass of complexity serves to obscure a relative small number of underlying principles and strategies that define success. ‘Someone, somewhere solved your problem’ is an oft-used TRIZ aphorism. We now believe we can extend that aphorism to include the full gamut of human emotions.

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Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

2. Question

What car was the first in the world to feature self-adjusting brakes? What about automatic lubrication? Or a ‘push-button’ gearbox? What about dynamic power steering?

3. The answer

In all four cases is the Ford Edsel (Figure 1). One of the biggest commercial disasters in the history of business. Supposedly Henry Ford’s final legacy. So proud of it, he named it after his son. How can someone who knows the industry so well – nay, someone who to all intents and purposes invented the industry (quite literally ‘the machine that changed the world’) – have got things so drastically wrong?

4. The story is

Of course, now the stuff of legend. Taught as a classic ‘how not to’ on just about every MBA business or marketing course. But, to be honest, none of those discussions has ever presented a truly coherent case for the failure. Sure enough there is
speculation about getting the pricing wrong, or mis-positioning the brand, or about how the economic recession at the end of the 1950s causing customers to shift to smaller cars, but somehow there just doesn’t seem to be a clear story to tell.

4.1. Ford Edsel

Something else we can notice about all of the features of the Edsel listed above were totally consistent with what the TRIZ trends would have said were definite moves towards a more ideal automobile. A suite of Evolution Potential plots of the car and its primary sub-systems reveals that all of the technology jumps occurred in directions consistent with the TRIZ Trends Of Evolution – Figure 2. The ‘voice of the product’ apparently got it wrong when it came to the Edsel.

The kind of extensive media coverage Tata Nano received right from the day it was announced through the entire period until the first units were handed over to the owners was something that its competitors dreamed of. However, after two years of launch, the Tata Nano manufacturing plant at Sanand in Gujrat, India found itself running at around 20% utilization. The Nano has swerved from one crisis to another. There was opposition to Tata’s original plans to site the factory in West Bengal, forcing a last-minute scramble to switch the site to Sanand.

It opened eventually, but not enough cars came off the production line to meet a huge surge of early orders. The orders then petered out. To make matters worse, a few cars burst into flames, raising fears about the Nano’s safety. Sales, which had been predicted to be 20,000 a month, fell as low as 509 in November 2009. Sales recovered to 10,000 a month in the spring, but fell back again to 3,260 in July,2010 amid a slump in the Indian car market caused by rising interest rates and fuel prices. Today, while the Nano story continues, the general consensus is that the ‘1 lakh car’ has been an overwhelming failure.

5. The Autonomous Car

Bringing the automotive industry right up to the present day, and we see much of the media in the attention being devoted to Google’s ‘autonomous car’ project – Figure 4. Again, from a Voice Of The Product perspective, the appearance of the project is entirely consistent with several of the TRIZ evolution trend heuristics: adaptive controllability algorithms, increased context responsiveness and reducing human involvement to name but three of the Trends found in Reference 1.
Google has wisely designed the ‘self-driving’ capability such that the technology can be readily ported to different vehicle platforms. The technology that makes vehicle autonomy a possibility, however, is anything but new. The General Motors Firebird II in 1956, was one of a quartet of concept cars to feature autonomous driving capability. The Firebird II was a more practical design than the other three Firebird designs: a four-seat, family car.

It featured a low and wide design with two large air intakes at the front, a high bubble canopy top, and a vertical tail fin. Its exterior bodywork was made entirely of titanium, had an engine output of 200hp, and to manage exhaust heat, ducted the exhaust gases through a regenerative system, which allowed the entire engine to operate at nearly 538 °C to markedly increase energy efficiency both directly and indirectly by using the waste heat to power the vehicle accessories. Other significant firsts on the car were the first use of four wheel disc brakes and a fully independent suspension.

From an Evolution Potential perspective, the Firebird II (Figure 5) should have been another sure-fire winner, even though it was only ever shown to the public as a concept vehicle.

5.1. Why?

Edsel: To begin to answer the failure question, it is worth examining the story of the development of the car in a little more detail. Read up on the history of the car and you will quickly learn that it had a rather long gestation period. The first market research and designs were in fact commissioned and conducted in the early 1950s. Actual launch of the first Edel’s onto the road, however, didn’t take place until September 1957 (on so called ‘E-Day’ in the US).

The Edsel was positioned in such a way as to squeeze into the company’s marque hierarchy between Ford and Mercury. As such its target market was largely going to be families and mid-level white-collar manager-types. Typically, therefore, people in their thirties. Take a look at Figure 6. This is a generational cycle picture taken from the works of Strauss & Howe[2]. This particular one features the Edsel. It also features two key data points on the age-date grid; the first – the point on the left – shows the period during which the market research on the target market was conducted. The second then shows the point at which the car was launched onto the market.

Sure all of the elements of the failure cited in the literature contributed to the failure of the Edsel, but if we are looking for a single root contradiction from which all of those other elements arise, then this looks like a pretty compelling case. The Edsel made the very simple mistake of missing a generational shift[3]. The Voice of the Product was right, but the selection and presentation of the ideas emanating from that Voice were falling into the wrong ears.

5.2. Nano

Nano’s price, which was supposed to be its USP, is largely now credited as one of the major reasons behind its poor sales. For majority of Indians, owning a car is not about utility or mobility; it is a dream, ambition and status symbol; just like a house. So, the low price of Nano does not turn it into an asset. It becomes more like a commodity. Also, the initial marketing and promotion of Nano gave the average consumer the idea that it was a car for the masses, much better than it was designed to be.
owning a Nano would somehow be a confirmation of their poverty in the eyes of family, friends and neighbours, and not a way to get out of it. Ironically, a big number of Nano’s buyers buy Nano as their second or third car after already owning another car. To make matters worse, the re-sale car market gives stiff competition to the Nano. A 3-4 year old used car originally costing 3-4 lakh in on-road price (like Chevrolet Spark and Maruti Alto) can pose a stiff challenge to Nano given the relative price-parity that emerges when it comes to re-sale. For instance, Nano’s Mumbai on-road price for Std BSIII model pegged at 1.51 lakhs is a few walks away from the Rs.2 lakh plus used-car-version ‘Spark’.

The key thing to notice in the space between these two data points, then, is the crossing of a generational divide: When the Edsel was being designed, the primary market was the tail-end of what these days has become known as ‘the greatest generation’. This is the ‘Hero’ generation that successfully came through the Depression in the 30s and then World War II. Alas, when the Edsel was finally launched onto the market, the Hero’s were older (and therefore quite likely to have moved upmarket to Lincolns, Oldsmobiles and Cadillacs), and a new generation of ‘Silents’ was now the most likely to be the customers for the car. As is the case in every generational shift like this, what one generation likes, the next is almost inevitably will not. And the rest is history.

Section headings should be left justified, bold, with the first letter capitalized and numbered consecutively, starting with the Introduction. Sub-section headings should be in capital and lower-case italic letters, numbered 1.1, 1.2, etc, and left justified, with second and subsequent lines indented. All headings should have a minimum of three text lines after them before a page or column break. Ensure the text area is not blank except for the last page.

5.3. Firebird II

Back in the 1950s, and indeed right up until the end of the 20th Century, ‘cars’ were synonymous with ‘freedom’ for any Western teenager. People grew up to love cars and love driving cars. A ‘self-driving’ car contradicted wildly with this social ‘DNA’. Why would someone that loves driving hand over control to an anonymous, mysterious piece of automation? Overwhelming they wouldn’t. Ask any Baby Boomer (born 1945-1962) or Generation X (1962-1981) individual. Ask a member of the later Generation Y (1982-2001), however, and freedom in their teenage years had everything to do with the Internet, and almost nothing at all to do with cars. A self-driving car to this generation is nothing but upside, because if their car (if they deem to even own one) is busy driving itself, it gives them more time to do all of the essential social media tasks they’ve devoted a considerable portion of their brain capacity towards. Firebird II, in other words, was two generations too early.

6. Universal Intangibles

One of the central tenets of the TrenDNA[4] process is that the best way to understand the behaviour of people is to not engage with them directly. 95% of Marketing budgets are wasted (the methodology says) because marketers for the most part ask the wrong questions, and no matter how cunning they are about eliciting the answers they think they need, they are far more likely to come away from an interview or observation of a potential consumer with a whole set of inaccurate clues than with anything that will help them create the ‘next big thing’ they think they’re after.

Right at the start of the TrenDNA process sits the ‘simple’ Outcome Map template (Figure 7). Even though the overall process tells users that they can start pretty much anywhere amongst the different clue generating tools, we tend to start here (and named it ‘tool 1’) because if we get this part of the process wrong, everything else we do downstream is likely to be skewed in the direction of wrong too.

Oftentimes, newcomers to the process worry that the things they write into the template are merely ‘their assumptions’ about what’s driving the behaviour of their target customer rather than any kind of truths that will end up determining their actual behaviour. True, the tool cannot tell us everything. It cannot, for example, give us a precise steer on which of the things we write into the template are more or less important than others in the eyes of each target customer segment. But – and here’s the crucial part – the things we write down, because they focus on ‘outcomes’, don’t need direct involvement of the customer because they are all universal.

‘Good reason’, tangible outcomes are finite because, think about the relatively small number of function and attribute categories there are in the TRIZ-originated Function Databases, the number of functions that are available are both known. And, moreover, are known to be very stable over time. If the rate at which the SI research team adds new ways of delivering a function is ‘slow’, the rate at which we add complete new functions is practically glacial. The point here being that we could inadvertently miss something off the tangible side of the Map, but our only logical reason for such an error would be that we failed to adequately check through all of the already known possible tangible functions.

When it comes to the (more important) ‘real reason’, intangible side of the Map, the level of uncertainty about whether or not we have been comprehensive when trying to describe all of the emotional drivers in a given situation is
understandably greater. Simply because the world of emotion-related functions and outcomes has not had nearly the same level of effort devoted to mapping the world than the tangible world has had. The world right now is at a stage where for the majority of industries, designers and marketers are still stuck trying to squeeze the last drop out of the tangible outcome story, rather than explore and properly map out the relatively desert-like intangible side.

The primary thesis of this paper — in true ‘someone, somewhere already solved your problem’ fashion — is to begin the journey through previous research from around the world, towards a correspondingly ‘complete’ list of all of the intangible functions that we might look to include in what we expect will eventually come to be a ‘comprehensive’ check-list.

Having now had the benefit of running over a decade’s worth of TrenDNA (or its constituent parts at least) workshops with clients, we know that if we merely collated all of the outputs written into the intangible side of the Map from all of the sessions, we’d already be somewhere close to ‘comprehensive’. We know this because we see how many times groups from very different sectors end up drawing what is essentially the same short list of emotional drivers — the customer wants to be cool; they want peace of mind; they want confidence; they want to do the best for their family. The same things over and over again.

7. So who has trodden this path before us?

One good answer seems to be the underpinning research that has in recent times been popularised as Self-Determination Theory (SDT)[6]. SDT is centered on the belief that people have innate psychological needs that are the basis for self-motivation and personality integration. Human nature, according to the theory, shows persistent positive features, that the theory calls "inherent growth tendencies."

SDT identifies three innate needs that, if satisfied, allow optimal function and growth:

- **Competence** - Seek to control the outcome and experience mastery
- **Relatedness** - Is the universal want to interact, be connected to, and experience caring for others
- **Autonomy** - Is the universal urge to be causal agents of one's own life and act in harmony with one's integrated self; however, it is about 'being in control' and does not mean to be independent of others.

These needs are seen as universal necessities that are innate, not learned, and seen in humanity across time, gender and culture.

7.1 Three Essential Elements to Theory

SDT advocates and developers, Deci and Vansteenkiste claim that there are three essential elements of the theory:

- Optimal development and actions are inherent in humans but they don’t happen automatically

To actualise their inherent potential they need nurturing from the social environment. If this happens there are positive consequences (e.g. well being and growth) but if not, there are negative consequences. So SDT emphasises humans’ natural growth toward positive motivation.

In terms of the Figure 7 Outcome Map, what SDT basically tells us is that the universal elements that form the basis of the two right hand columns of the Map are the trio of drivers Autonomy, Competence and Relatedness – Figure 8.

![Figure 8: SDT-Based Universal Intangible Drivers](image)

Any and all of the things we’ve seen written down by groups essentially fits into one or a combination of these three, with one exception. A subtle but important element that we need to venture into the work of Edward Matchett[6] to fully unravel. Matchett conceptualised ‘Meaning’ as the highest level human driver. Whatever we do, Matchett concluded after his lifetime’s work studying human problem-solving behaviour, is fundamentally driven by a desire to do that which is ‘meaningful’.

Adding SDT to Matchett’s work presents us with a quartet of innate intangible human drivers, that we have come to relabel slightly as the ‘ABC-M’ model (Figure 9), which conjectures that intangibles all distill down to our parallel needs for Autonomy-Belonging (‘renamed from ‘Relatedness’ in the SDT model) – Competence-Meaning.

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We think this quartet is an important foundation-stone in the TrenDNA intangibles story, serving as what we might think of as a meta-checklist of things to make sure we’ve considered during any Outcome Mapping activity.

From an innovation perspective, we also conjecture that one of the primary criteria determining whether an innovation attempt will pass an intangibles test is that all four elements in the ABC-M model should be perceived by the customer to be better with the innovation attempt than they were before the innovation attempt appeared.

Knowing that the trio of automotive innovation attempt failures recorded in this paper could never serve to ‘prove’ the truth of this ‘ABC-M all get better’ conjecture, we nevertheless hope that by using them as exemplars we can at least start to convey to readers a level of intrigue that causes them to apply the model to other innovation attempts, failed or successful, within their organisations or industry in order to test the validity or otherwise of the model. From the Systematic Innovation company perspective, having been testing the model for close to a decade now and not finding any exceptions, we have largely convinced ourselves that the model needs to be present during any innovation project involving humans in either customer or supplier role in order to help validate whether a proposed ‘solution’ is merely something that satisfies the TRIZ-like tangibles, or whether it also ticks the intangible success criteria.

And so, one last time to our three case studies:

7.2 Edsel:

Because the Ford Marketing team failed to identify the generational shift that had occurred between the conceptualisation and commercial realisation of the car, what they believed to tap into the Belonging needs of their target customer, was almost 180 degrees out of sync with what the actual generational cohort that followed wanted to be in control of. Autonomy goes up for any car drives itself, the driver has more time to be in control of brake better than any piece of Detroit technology, so the prospect of the vehicle taking away all of their control was very likely anathema. Swing forward to the present day and the prospective Generation Y customer, and an autonomous car has a far greater likelihood of being successful because it permits a driver’s sense of Autonomy to be increased, because when the car drives itself, the driver has more time to be in control of their smartphone and all the other, more important, things in life they wish to be in control of. Autonomy goes up for any driver that has no interest in actually driving.

7.4 Firebird II:

As far as the 1950s driver as concerned, a self-driving car represented a major negative mark in the Autonomy element of the ABC-M model. Even as late as the 1990s, many US car buyers still refused to have (tangibly better) ABS braking options in their vehicle since drivers felt they ‘knew how to brake better than any piece of Detroit technology’, so the prospect of the vehicle taking away all of their control was very likely anathema. Swing forward to the present day and the prospective Generation Y customer, and an autonomous car has a far greater likelihood of being successful because it permits a driver’s sense of Autonomy to be increased, because when the car drives itself, the driver has more time to be in control of their smartphone and all the other, more important, things in life they wish to be in control of. Autonomy goes up for any driver that has no interest in actually driving.

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Dynamic and Semantic Database of Effects for Technology Transfer

Tiziano Montecchi\textsuperscript{a}, Davide Russo\textsuperscript{b,*}

\textsuperscript{a}Bigflo srl, via Galvani 2E, Dalmine 24044, Italy
\textsuperscript{b}University of Bergamo, viale Marconi 5, Dalmine 24044, Italy

* Corresponding author. Tel.: +39-335-783-4961; fax: +39-035-205-2077. \textit{E-mail address}: davide.russo@unibg.it

Abstract

A dynamic and semantic database of effects has been developed. Scientific effects databases are collections of effects that can be used in technology transfer for identifying alternative ways to perform a same function. Usually, effects consist in static lists that searchers have to manually browse imagining which effects are useful for their applications. In TRIZ community, more advanced tools (function-oriented), as the pointers to effects, have been developed. These tools link physical effects to a narrow set of functions contained in the database. These functions are not always perfectly the function required by searchers and in some cases the matching is inexistent. Another drawback is that also these databases are static. Indeed, the links between effects and functions are defined a priori and they are independent from the application field in order to gain a general validity. Pre-defined links can lead to the suggestions of physical effect unusable for a specific field or in the worst cases usable effects can be missing.

To overcome limitations, the authors have developed a dynamic pointer to physical effects that integrates a new library of effects and a semantic search engine called Kompat. It works with any function (pair verb-object). The link between function and physical effect is created by searching on technical or scientific literature, such as patents. The semantic engine automatically extracts all documents containing the physical effect to perform the selected function, and creates a list of Effects linked to the initial function. The number of documents is also an index of the feasibility and the degree of maturity of the technology using that effect. Technology transfer is done comparing the list of effects already extracted in our initial search domain, with effects coming from a larger pool of documents; these effects are not yet known in starting domain but already used in others for performing the same function.

This article presents an application of the proposed dynamic effects database to a case study of eye inspection with the goal of identifying new promising technologies for measuring the temperature of the cornea.

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Keywords: Technology transfer, effects database, patent, TRIZ, semantic search

Nomenclature

<table>
<thead>
<tr>
<th>CPC</th>
<th>cooperative patent classification</th>
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<tr>
<td>O</td>
<td>object</td>
</tr>
<tr>
<td>PE</td>
<td>physical effect</td>
</tr>
<tr>
<td>TT</td>
<td>technology transfer</td>
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<tr>
<td>V</td>
<td>verb</td>
</tr>
</tbody>
</table>

1. Introduction

Nowadays, Technology Transfer is an increasingly present activity, as confirmed by the interest of European commission [1] and also well-known patent offices such as the World Intellectual Property Organization (WIPO). In particular, WIPO provides numerous technology transfer webpages [2] and landscape reports [3] that present state-of-the-art search for relevant technologies in areas of particular interest such as public health, food security, climate change and environment. The growth of TT practices is also confirmed with the dynamic laws of evolution identified by Altshuller [4], that we report in the following:

\textbf{Transition from macro to micro level}

\textit{The development of working organs proceeds at first on a macro and then a micro level. The transition from macro to micro level is one of the main (if not the main) tendency of the development of modern technical systems. Therefore, in
studying the solution of inventive problems, special attention should be paid to examine the "macro to micro transition" and the physical effects, which have brought this transition about.

Increasing the S-Field involvement

Non-S-field systems evolve to S-field systems. Within the class of S-field systems, the fields evolve from mechanical fields to electro-magnetic fields. The dispersion of substances in the S-fields increases. The number of links in the F-fields increases, and the responsiveness of the whole system tends to increase."

According to these laws of evolution, technical systems evolve integrating more S-field interactions, which implies that different technologies work together for achieving the same goal and they can be replaced according to the transition from macro to micro-level.

Among all the strategies for making technology transfer one of the most promising is based on patent search. Typically, searchers use the traditional patent search methodology that is an iterative process combining keywords and patent classes and in some cases inventors, applicants and backward-forward citations. In particular, the European Patent Office (EPO) proposes a patent search procedure based on three steps for searching prior art technologies:

1. Finding the right keywords: think of search terms which better describe your idea;
2. Product searching: find out what is already on the market that is similar to your idea (prior art) and that solves the same problem (competing art);

The main limitations of this approach is that searchers have to be experts in patent search to choose the right keywords and patent classes and they have to know the technology before starting to search for it. These drawbacks make more complex and time consuming the patent search.

In TRIZ community, radically different approaches based on the functional search have been developed for supporting technology transfer. An excellent integration of the functional search (Action + Object) with physical [5-8], chemical [9] and geometrical [10] effects, is a tool called Pointers to Effects. It was introduced in the problem solving process by Altshuller [4]. He studied the link between engineering parameters (i.e., increase the temperature) and physical and chemical effects that can be used to reach a certain goal (i.e., electric or electromagnetic or thermal phenomena). For example, according to this tool, the specific function cracking a nut can be easily translated into a more general function “break a solid” to choose between many different effects listed inside the pointer to Effects DB. Even if this tool is easy to use because design oriented, it lacks of completeness. Not all specific functions have a corresponding pointer to effect and some pointers are still difficult to be exploited because too vague (i.e., “change a dimension”, “detect surface properties”, “detect volume conditions”, etc.).

From 70’s, Pointer’s idea has evolved in several research works such as Function Oriented Search (FOS) [11]. FOS is a 7 steps procedure based on: the identification of the function we want to improve, the abstraction of this function, the search of those technological areas where the abstracted function is performed for solving similar problems and finally the extraction of best technologies and experts. Results are very dependent on the abstracted function and the search of technological areas.

Pointer to effects has also evolved in commercial products such as Knowledgist [12], and Goldfire Innovator [13] that offers a collection of over 9,000 cross-disciplinary scientific effects. All these existing tools are static because they are based on a prebuilt database that has a fixed set of general functions, a fixed set of effects and fixed links between them. In this article, the authors present a dynamic and semantic database of effects. At difference from existing tools, our database has a physical effects library integrated with a semantic search engine. All existing verb-object pairs can be used as starting function. The links between effects and functions are not prebuilt, but they are extracted by the semantic search engine from documentary sources (such as patents, scientific and technical literature, etc.). Section 2 presents the new dynamic database of effects, section 3 reports on the TT methodology, and an exemplary case study is given in section 4 to show the application of the methodology to the measurement of cornea temperature during eye inspection.

2. Dynamic and Semantic Effects Database

The proposed dynamic effects DB combines together a prebuilt physical effects library and a semantic search engine. The Physical Effects (PE) library, used to identify alternative technologies, is the core of Kompat. This library has been created collecting and revising scientific effects taken from different pointers to effects and commercial physical, chemical and geometric effects databases. In particular, this library contains a list of effects and technologies classified according to the type of interaction: mechanical, acoustical, thermal, chemical, electrical and electromagnetic. Each effect is associated to a list of words. For example, the concept of “mechanical/compression” is linked to nouns such as “pressure”, “compression”, verb such as “to press”, “to compress”, “to push”, adjective such as “compressible”, technologies (such as “press machine”, “pressure roller”, etc.) and other technical parameters (such as “compressive coefficient”, “maximum tensile stress”) and units of measure (“Pa”, “bar”, “atm”, “psi”, etc.).

The semantic search engine is used for creating the link between these effects and the function that searcher wants to perform, e.g. crack a nut. In particular, the search engine launches hundreds of queries in order to find patents that describe effects used for performing the input function. Queries are generated for searching the following concept:

Verb + Object + Physical Effect.

Where verb (V) and object (O) describe the function or the problem to be solved, the effect (PE) is contained inside the library. For example:

- crack + nut + compression
- crack + nut + gravity
- crack + nut + explosion
- crack + nut + ...
Over 10 different semantic algorithms are used to improve patent search increasing precision and recall. In order to increase the precision of results, words having multiple meanings are disambiguated. The semantic search engine proposes the list of all the meanings for both the verb and the object and the searcher has to choose the desired meaning, e.g. for nut we have many meanings such as the hard-shelled seed or the small metal block with internal screw thread. Another functionality for increasing precision is the automatic identification of relevant CPC patent classes for limiting the search to the specific concept (V+O+PE). In order to increase recall, a semantic expansion of the query is used, based on generating synonyms (break, check, …), useful related words (chap, craze, …) and their linguist variants (cracks, cracking, cracked, …) for searching the same concept (V+O+PE).

3. Technology Transfer methodology

As shown in other publications [15-17], this dynamic effects database can be used to perform TT. The TT procedure consists of 2 steps:

- State-of-the-art construction: alternative technologies are identified and divided in technologies existing at the state of the art and new technologies not yet used for the domain under investigation.
- Technology Transfer: new technologies applications are searched in different technological areas.


Given a specific domain, the goal of this phase is to identify both the technologies existing at the state of the art of a specific context and new technologies not yet used. Thanks to the dynamic effects database, the searcher does not need to know or image the alternative technologies before to search them. Searchers have to translate the function they want to perform in form of verb-object couple, e.g. crack nut.

As result, the dynamic database gives back a map of physical effects and technologies classified according to the interaction field: mechanical, acoustical, thermal, chemical, electrical and electromagnetic, see figure 1. The link between effects and the initial function is represented by the number of patents mentioning the effect itself.

Effects are divided in 2 classes:

- Existing effects: when patents mention an effect for performing the initial function, this effect is considered already existent for the domain under investigation. Each effect is associated with the number of patents, see fig. 1. The number of patents related to each effect is also an index of patent density. Effects with high number of patents are more reliable but this implies also more
competition between players. On the contrary, effects with low number of patents represent pioneering applications but still already implemented by someone.

- New potential effects: when any patent does not mention an effect for performing the initial function, this effect is considered new because it is not yet used for performing the desired function, e.g. crack nut. These effects represent the new patentable opportunities that we call White Space Opportunities (see fig. 1).

For the domain under investigation, patents found represent the link between the function and the effects. Patents found for each effect can be used as the starting point for assessing the technology, acquiring knowledge about a specific technological area, extracting patent trends, monitoring direct and new competitors and more in general supporting decision making activities. For the sake of brevity, these analysis are not presented in this work (this topic is treated in Russo et al. [18]). In the domain under investigation, those effects with zero patents are not linked with the initial function. The next step is based on searching applications of these new effects in different technological areas.

2. Technology Transfer.

The goal of this phase is to search if the White Space Opportunities (WSO) are already used in different technological areas for performing a similar function. In other words, patents belonging to other domain are the link between WSO effects and the function. This search is based on the abstraction of the function (crack + nut) through the generalization of the object (e.g. crack + seed, fruit, shell, plant organ, natural object, ...) [15]. Starting from the abstracted function, the semantic search engine launches new queries for searching WSO effects. If at least one patent of another domain describes the use of the WSO effect for performing the abstracted function, this effect is a potential alternative to be transferred in the initial domain.

4. Technology Map

During a refractive surgery, before the ablation, the cornea has to be cooled down. During, this process, the temperature of the cornea is continuously recorded by an infrared camera in order to understand when the corneal temperature is below the baseline. The following CPC patent classes have been used to limit the context of the application:

- A61B3: Apparatus for testing the eyes; Instruments for examining the eyes.
- A61B5/6821: Arrangements of detecting, measuring or recording means, e.g. sensors, in relation to patient’s eye.
- A61B8/10: Diagnosis using ultrasonic, sonic or infrasonic waves for eye inspection.

1. State of the art construction

The function we want to perform is “measure the temperature” of the cornea.

- For the verb “measure” among all the meanings we choose “determine the measurements of something or somebody, take measurements of”. This verb is semantically expanded by the patent search engine with other verbs such as: detect, monitor, determine, sense, measure, etc.

- For the object “temperature” we choose the meaning “the degree of hotness or coldness of a body or environment (corresponding to its molecular activity)” that is expanded with terms such as: heat, boiling point, curie point, physical property, etc.

After the selection of desired meanings, the patent search engine launches an automatic search strategy for each effect contained inside the PE library. For example, for the physical effect of Ultrasound, we will search for:

- ultraso* or ultra so* or ultra-so* or *sonography or echography or (((### khz or ### khz or ### khz) and (sound*)))

Where:
* Truncation replacing any number of characters
# Truncation replaces exactly one character

The output of the dynamic effects database is the list of PE for “measuring the temperature of the cornea” divided in: existing effects (e.g. infrared) with number of patents > 0 and WSO effects (e.g. Doppler effect) with number of patents = 0. 8 existing effects have been identified by the database. All the remaining effects of the database (over 200 effects) are WSO effect because no patents describe them. By a manual check of the found patents, 7 out of 8 physical effects are really used for measuring the cornea temperature, while the cryogenic effect is a false positive because the patent found describes the cryogenics as an effect for cooling down a cornea sample.

2. Technology Transfer

Among all WSO effects, 19 of them have related patents describing the use of these effects for measuring the temperature of objects in general. These patents belong to different domains. For this task, the search engine investigates patents outside the CPC classes related to the eye inspection searching inside the class G01 (related to measuring and testing) or the entire patent database. In figure 2, the 19 new potential effects for measuring temperature are highlighted in green. These are potential effects suitable for TT because already used for measuring the temperature but not for the eye inspection.

5. Conclusions

A dynamic pointer to effect database integrates a brand new PEs library with a semantic search engine. This database is a function-oriented tool that automatically suggests which effect can be used for performing a certain function searching for an application inside technical and scientific literature, such as patents. If patents found belong to the domain under investigation, the physical effect described is a known solution at the state of the art. Instead, if patents belong only to other domains, the physical effect can be used for Technology Transfer activity. The number of patents found is an index of the feasibility and maturity of the application. All physical effects suggested are also organized according to the
7 TRIZ fields: mechanical, acoustic, thermal, chemical, magnetic, electric and electromagnetic.

In addition, having the list of patents for each effect can be very useful for extracting further information. From the analysis of these patents we can understand which technologies are the most used and which ones are pioneering, who are the main players and which are the technological patent trends of a specific domain. Also for new transferable technologies additional information can be extracted from patents, such as who are the main experts, which are the most advanced domains, which are the potentialities and drawbacks.

The semantic search algorithms and the PE library are still under development in order to increase precision and recall of both technologies identified and related patents. The list of effects and related patents is the current automatic output of the dynamic effects database. This result can be represented in a Technology Map that consists of a concise overview of technological areas. This map together with additional information extracted by patents allows managers and experts to have a comprehensive and fast overview on the situation, increasing awareness and consistency of decision making.

Figure 2 Technology Map shows the effects existing at the state of the art and new potential effects suitable for technology transfer (in green). These results are a graphical representation of Kompat output obtained for the function “measure temperature”.

References

From a Toolbox to a Way of Thinking – An integrated View on TRIZ

Horst Th. Nähler\textsuperscript{a,}*, Barbara Gronauer\textsuperscript{b}

\textsuperscript{a}c4pi – Center for Product-Innovation, Rhönmalerring 30, 36088 Hünfeld, Germany
\textsuperscript{b}StrategieInnovation, Rhönmalerring 30, 36088 Hünfeld, Germany

* Corresponding author. Tel.: +49-6652-9928277; E-mail address: naehler@c4pi.de

Abstract

TRIZ is known as a powerful toolset for inventive problem solving. Its algorithms, methods and findings are applied to a wide range of engineering problems – experiences for the successful use in non-technical areas are published as well. The industrial application of TRIZ mostly starts with moderated workshops or trainings. Subsequently, TRIZ is often moved into the company’s own “warehouse of methods” and pulled out when needed. While this approach is straightforward and quite useful, it limits the potential of what TRIZ has to offer for innovation activities and product development processes of companies from all industries.

Hinged on the System Approach, 9-Screen-Model and Function Analysis, the paper describes how those operational aspects can be integrated into the strategic use of Trends of Engineering Systems Evolution (TESE) and S-Curve Analysis. This integrated view can be used to evaluate and expand the development potential for any engineering system. The paper is aimed at the TRIZ professional as well as the TRIZ newcomer. The professional gets a fresh view on TRIZ as a way of thinking and input for new approaches to strategic product development with TRIZ, trying to “connect the dots” in innovation. Those new to TRIZ will get a “helicopter-view” introduction to the spirit of TRIZ, which is more than a box full of methods and algorithms.

1. Preface

This paper is neither a scientific research, nor a case study. It is aimed at a high-level view on well-known TRIZ findings and tools, trying to give an alternative perspective on how TRIZ can contribute to a systematic innovation and product development process.

2. More than a Toolbox

Not long after the second World War, a young Russian named Genrich S. Altshuller, wanted to find out how to learn to invent. Until then, inventions were mostly described as result of accidents, luck or inborn genius of gifted people. As a counterpoint, Altshuller’s attitude was “If a Methodology for Inventing did not exist, one should be developed” [1]. So the Theory of Inventive Problem Solving was brought to life and continues to be an invaluable and unrivaled resource of methods, tools and algorithms to tackle inventive problems based on the findings of past break through inventions and the condensed strategies of histories most gifted problem solvers.

In today’s corporate environment, TRIZ is rightly valued as a toolbox for inventive thinking, having positive effects on problem solving capabilities of groups and individuals. It’s findings enable systematic approaches to otherwise “fuzzy” topics. Reports of the use of TRIZ and presented case studies are mostly split into the operative use of certain methods, which are pulled out of the Toolbox when needed, and strategic considerations that are mostly detached from the operative work [2, 3, 4, 5, 6]. However, the findings of Altshuller, his colleagues and successors are worth a more thorough look at what TRIZ actually offers for the task of “making things better”, also known as “Product Development”.

One of the stories that MATRIZ-students frequently hear, is that Altshuller gave out the task to his students to describe the most important notion of TRIZ in only one sentence. It is said that Altshuller preferred the following description for the essence of TRIZ (loosely quoted):
“TRIZ is the realization that Engineering Systems evolve according to objective, universal Trends and Patterns, which can be taught and learned.”

All tools and methods of TRIZ are based on this finding, and those universal trends and patterns represent the “Voice of the Product” which is independent from the individual and true for all engineering systems [7].

While this statement might be too ambitious for some, it implies that TRIZ is an emerging science that deals with the evolution of engineering systems. As such, TRIZ has much more to offer than a toolbox for problem solving. This paper discusses some generic aspects of TRIZ that might lead to a broader, more open view on the topic of product development viewed through the “TRIZ-lens”.

3. Everything is a System

One of the basics of TRIZ is the “System Approach” (also known as Multiscreen Approach, Talented Thinking, 9- Windows etc.), according to which each system is made of Subsystems and is embedded into (or surrounded by) Supersystems. This structuring aspect is enriched by a timeline, that generally describes past, present and future (or before, during and after) for the System, Subsystems and Supersystems [8, 9, 10].

As simple as this scheme is, as powerful are its conclusions: The first task of a TRIZ project is to define: “What is the system we are dealing with?”. This definition sets the stage for the upcoming efforts, it has even the power to determine the level of inventiveness we are aiming for. We can easily imagine that there are huge differences if we call our system “Water Pump”, if we call our system “Water Treatment Plant” or if we define our system as “Ball Bearing inside Water Pump”. Each definition is valid, and all systems interact with each other and therefore depend on each other.

Fig. 1. Hierarchical System Structure.

While it is common to define the product that a company sells as the system, the Multiscreen Approach always calls for consideration of Supersystems as well. Even a producer of ball bearings should not hesitate to watch higher level Supersystem developments to evaluate changes that might affect one’s own products. From this point of view, the definition of the System to work on decides if we are dealing with disruptive inventions or incremental inventions, with the terms disruptive and incremental being relative as well. As a pump producer we are free to zoom into the pump and work on e.g. the bearing to incrementally improve the pump without changing the overall principle of moving water. At the same time, we are free to zoom out to the water treatment plant and ask questions about changes on the plant level which might affect our pump - even changes that renders the pump unnecessary. Those changes might be quite disruptive for the pump producer, while the operator of the plant only sees this change as a minor improvement inside the whole plant.

The freedom to choose the system level according to the task, aim and expectations holds great power and consequently leads to a more open and unbiased look on systems [11]. We understand that our current product is just a part of bigger picture and it might be only one of many ways to perform a certain function. It even leads to the realization that each system, like a living organism, is dependent on its surroundings. If the boundary conditions change, the system will have to react and adapt in order to survive. Examples of disappearing industries due to changes on Supersystem-level are manifold [12, 13, 14].

4. “What does it do?” - Modelling of Systems

The Multiscreen Approach can be used in multiple ways, but as a starting point it is aimed at the definition of the system and an analysis of its structure and history, identifying significant changes in the past [15]. Another tool, which can be linked seamlessly with the Multiscreen Approach, is the TRIZ Function Analysis [16]. This tool helps to assess what the components of a system (or the “Subsystems”) actually do with each other and how they interact with components in the environment of the system (or the “Supersystems”). The TRIZ definition of a Function itself [7, 17] objectifies the view on a given system: What does the system actually do? Which parameter of the target component is changed? Inherently, the question of “which different action principle can change the same parameter as well? What could be an alternative, maybe more efficient way of performing that function?” leads to an objective look at new opportunities.

Fig. 2. Nested Function Model.

Knowing that every system is made of Subsystems, which themselves are again made of Sub-Subsystems etc. inevitably leads to a “Matryoshka”-like image, where Function Models can be build on different levels and linked throughout the
"system tree". This enables a very detailed analysis and scalable representation of complex systems, starting from a high System-level and going down to an arbitrarily detailed Sub-Sub-(...) System level (see Fig. 2) [16].

Again, the level at which we build function models determines the level of invention (disruptive or incremental) we are aiming for. With such a "Nested Function Model" we have a solid base for evaluating changes on several levels. To get the most out of Function Models, we should not stop modelling only our product that we sell, but rather model higher level interactions were our product itself is only one of many components and might be subject to trimming or other Supersystem changes, opening our eyes for a bigger picture, e.g. what the end user actually wants or in which context our product is used. Consequently, we might move from "customers don’t need a drill, they want holes" to "customers want to have decorations on their wall", depending on the level at which we model the situation (see Fig. 3).

If we further expand the Function Analysis into the past (according to the time axis of the Multiscreen Scheme) and model previous versions of our System with the respective Sub- and Supersystems, we are able to assess how our system evolved until now, making it more easy to identify applicable Trends of Engineering Systems Evolution (also see Fig. 4 and Chapter 5).

By consciously considering such interdependencies we can actively monitor and evaluate market situations and technological changes, actively mapping out future actions. By focussing on different system levels, we can decide to asses for incremental or disruptive changes. From a strategic viewpoint, Function Models on different levels help us to plan short term and long term measures alike [16].

5. Learning from the Past to shape the Future – Trends of Engineering System Evolution

As stated in Chapter 1, the Trends of Engineering Systems Evolution are a crucial base of TRIZ. While Altshullers generic 9 Laws of Evolution [8] were mere statements, recent works have developed those laws into the System of TESE [7]. As of 2010, eleven main Trends have been identified that are structured within a hierarchical system (see Fig. 5). The trends represent statistically proven directions in which Engineering Systems evolve. Each Subtrend contributes to a higher level Trend, each Subtrend is a specific way an Engineering System evolves along a Trend line. While still in development, the TESE represent useful universal strategies how to make things work better, based on best practices from the past which have been observed across all kinds of Engineering Systems.

The topmost Trend is the Trend of S-Curve Evolution. Being on the highest level, this Trend can be considered a universal, basic law: Each Engineering System evolves along an S-shaped curve that has distinct phases. Each S-Curve describes the evolution of a so-called Main Parameter of Value (MPV) along a time axis. An MPV is a key attribute or outcome of a product or service that is important to the purchase decision process [7, 18]. So MPV represent system characteristics for which the customer is willing to pay money. As a system evolves, MPV increase through S-Curves (incremental) as well as jumps in S-Curves. Those jumps again represent disruptive changes for the system under consideration (e.g. speed of an airplane increased through the jump from propellers to jet engines). Speaking in TRIZ-terms, the jumps indicate where contradictions have been solved to move an Engineering System forward for the respective MPV (see Fig. 6).

As each system might have several MPV, those usually are on different stages on their respective S-Curve. An assessment of the MPV and their position indicates, how to push each MPV most effectively. This is possible because each stage of an S-Curve has its own recommendations based on the analysis of the most successful strategies of the past [7, 17].
The mere acceptance that each Engineering Systems evolves along S-Curves and jumps from one S-Curve to the other holds great value for strategic decisions. S-Curves make clear that each new invention has to go through a first "prototype"-stage and that a new system is likely to underperform in the beginning, compared to established "old" systems, but the new system has the potential to surpass the old system in the long run. The S-Curve also makes clear, that each system is bound to either being replaced by another system, being integrated into Supersystems or exist in degraded form after a new system takes over. It teaches us that change is inevitable, but that we are able to be aware of those changes and possibly drive them. Again, the Trends are true for all Engineering Systems, so the Trends can be applied to each System Level and therefore be used for either incremental changes or disruptive changes, depending on the point of view (see Fig. 7).

Another aspect that bridges the gap between the more strategic looking TESE and the operative Problem Solving Tools like the Inventive Principles or Standard Solutions is the fact, that each of the Principles or Standard Solutions are the building blocks of the TESE. They represent the actions through which Engineering Systems have evolved in the past and can be developed further in the future – no matter if the System is a tiny bolt inside a combustion engine or a complex paper production line. Newer studies work on enriching the TESE show us that we can actively shape the development of our Systems with winning strategies of the past. They tell us when to let go of “old” products and when to invest in improvement or disruptive change.

If we combine the TESE with Nested Function Models and the Multiscreen Approach, we are able to build a complete Product Map as a basis for assessing our systems on desired levels and plan future developments. Those aspects go far beyond the sporadic problem solving activities with the Contradiction Matrix or Standard Solutions when FMEA-, Six Sigma- or Value Engineering-projects brought up problems – they are a way of looking at Engineering Systems and the way they evolve. Multiscreen Thinking, Function Analysis and TESE combined can be a crucial part of designing an innovation process that is based on the best strategies for breakthrough solutions in the past. It is not a “be all, end all” methodology, but surely TRIZ is often underrated with respect to its strategic value and how it can significantly complement other strategic management tools.

6. “This is where the Real Work starts” - From Invention to Innovation

The powerful TRIZ is, it is still just an auxiliary means. Its findings and implications might be powerful to start thinking, inventing and designing consciously, but it alone does not guarantee market success. Looking at past B2C examples like “Nespresso”, the “iPhone” and “iPad” or more recent B2B products like the “Galaxy Drive” by Wittenstein or the “Twin CC8800” Crane by Terex, we have to accept that the invention, the idea, concept or even a working prototype is just the first step. The real work starts after the concept is decided: We’ll face lots of secondary problems, we need project management, funding, accounting, business models and marketing to turn an invention into an innovation. But TRIZ can cover our backs on this journey with its best practices from past breakthrough inventions. We can trust its findings and be more courageous about new developments as we can rely on proven strategies. It gives us strategic recommendations for each stage of the Product Lifecycle and tools to move an Engineering System forward consciously on any level we chose. TRIZ minimizes the chance of being surprised by an “unexpected move” from a competitor or by a start-up that is breaking the unwritten laws of the branch (just think of Uber, Tesla and the likes) and it can teach us to be innovative, driving and embracing change. TRIZ is more than a toolbox, it provides a different perspective on the Development of Engineering Systems and as such sparks a new way of thinking.

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USIT: A Concise Process for Creative Problem Solving
Based on the Paradigm of ‘Six-Box Scheme’
-- USIT Manual and USIT Case Studies --

Toru Nakagawa*a,*

*a Osaka Gakuin University, 3-1-13Eirakudai, Kashiwa, Chiba 277-0086, Japan

*Corresponding author. Tel.: +81-4-7167-7403; fax: +81-4-7167-7403. E-mail address: nakagawa@ogu.ac.jp

Abstract

USIT (Unified Structured Inventive Thinking) was originally developed by Ed Sickafus in 1985 as a concise whole process of creative problem solving and has been developed further since 1999 in Japan. In 2002 we reorganized all the solution generation methods of TRIZ into a System of USIT Operators. In 2004, I represented the whole USIT process in a data-flow diagram and realized it as a new paradigm for creative problem solving and named it the ‘Six-Box Scheme’. In 2012, I realized that what are really wanted by society are not individual methods but a more general way of thinking for creative problem solving. So I am proposing to integrate different methods of problem solving into a unified general methodology CrePS on the basis of the ‘Six-Box Scheme’. Hence, USIT is now regarded as a simple process for executing the CrePS methodology.

In the present paper, the USIT Manual was prepared and more than 10 published cases of creative problem solving have been documented along the ‘Six-Box Scheme’. The present paper discusses about (1) the Six-Box Scheme in comparison with the conventional schemes, (2) possibility of integrating diverse methods of creativity and innovation into CrePS, (3) overall process of USIT, especially how to support the idea generation step, (4) documenting various case studies executed with other methods in the USIT Six-Box Scheme, (5) further issues and tasks for pursuing the new vision/target of establishing CrePS.

Keywords: USIT; Creative problem solving; Six-Box Scheme; CrePS; Case studies

1. Introduction

USIT (Unified Structured Inventive Thinking) was originally developed by Ed Sickafus in 1985 as a concise, consistent process of creative problem solving [1, 2] and has been developed further in Japan by the present author. USIT history in Japan can be characterized by the following four stages:

<table>
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<tr>
<th>Nomenclature</th>
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<tr>
<td>TRIZ</td>
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<td>USIT</td>
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<td>CrePS</td>
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* The year of USIT development (at that time called SIT) was written as 1995 in Sickafus (1999) [2]. But Sickafus writes in a recent communication: “the 1999 paper is a typo. I began studying the Israeli SIT in 1985 and later that year began teaching a modified version of it in Ford Research Laboratory. That program continued until my retirement in 2000.”
The present author introduced TRIZ into Japan since 1997 and also USIT since 1999, and tried to improve them further. Initially, we regarded USIT as a 'Simplified TRIZ' and used it as the key method of the 'Slow but Steady Strategy of Introducing TRIZ into Japan' [3] in contrast to the 'Rapid and Drastic Strategy' which was prevailing at that time in the world.

In 2002 we reorganized all the solution generation methods of TRIZ and USIT. All TRIZ tools (e.g., 40 Inventive Principles, 76 Inventive Standards, Trends of Evolution of Technical Systems, etc.) were once decomposed into individual suggestions and then rebuilt into a System of USIT Operators, which are composed of 5 main Operators having 32 sub-operators [4]. Then we regarded USIT as 'A simplified, unified, next-generation TRIZ'.

In 2004, the author represented the whole USIT process in a data-flow diagram (in place of a flow-chart) having 6 boxes, and realized it as a new paradigm for creative problem solving and named it the 'Six-Box Scheme' [5, 6]. This finding gave a solid basis for applying USIT in various areas.

In 2012, while considering about the future directions for us to proliferate TRIZ widely and deeply, the author realized that what are really wanted by society are not individual methods like TRIZ, USIT, etc. but a more general way of thinking for creative problem solving and the methods supporting it. And he called it CrePS ('General Methodology of Creative Problem-Solving and Task-Achieving'). He also found that the 'Six-Box Scheme' can form the common basic paradigm of the general methodology CrePS and can integrate and unify different methods of problem solving, including TRIZ, USIT, and many others, in a systematic way [7]. And hence, USIT is now regarded as a simple process for performing the CrePS methodology.

In the present paper, the USIT Manual [8] was prepared to illustrate the typical ways of performing the USIT process. And more than 10 published cases of applying creative problem solving have been documented along the 'Six-Box Scheme' in detail, and they form 'A Collection of USIT Case Studies' [9]. The case studies show the common nature of the main steps of the whole process and the effectiveness of the 'Six-Box Scheme' as the basic paradigm.

2. The Six-Box Scheme as a new paradigm of creative problem solving

The Six-Box Scheme [6, 7] is a framework representation of the general process of solving problems and achieving tasks creatively. It is defined by the dataflow representation, shown in Fig. 1.

![Fig. 1 Six-Box Scheme as the new paradigm of creative problem solving (CrePS/USIT) [6]](image)

It is fundamentally characterized by the six boxes, which represent the information to be obtained at the specified stages of the procedure. The arrows stand for the process for obtaining the information requested for the next box, on the basis of mainly the information of the previous boxes and also of various other background knowledge relevant or even seemingly-irrelevant to the subject matter. The arrows show the main stream; it is natural in practice to have side streams for shortcuts, multiple paths, going back, loops, spiral motion, etc.

Distinguishing the Thinking World (i.e., four boxes in the upper half) from the Real World (i.e., four boxes in the bottom half) is an important concept introduced in this scheme. Problems start with the recognition in the Real World and should finish as concrete solutions implemented in the Real World, where the decision criteria need to reflect the value concepts and the actual situations of society, business, technology, etc.

On the other hand, the process of analyzing the problem and generating good and effective solutions should better be carried out in the Thinking World, where free, wide-scope, and creative ways of thinking are encouraged and guided.
with some methodology. This is a general consensus in practice and in theory of pursuing creative problem solving. At the interface of the two Worlds, Box 2 and Box 5 show the information to be handed-on between the two Worlds.

In the Real World, where problem solving starts, there are a large variety of activities, jobs, stakeholders, products, etc. running in parallel. Specific problems are recognized first (Box 1) in the Real World and then need to be defined well (i.e., sorted out, examined, selected, focused, stated, etc.) to be solved, and is handed-on to problem solving projects.

In the Thinking World, the specific problem (Box 2) should first be confirmed in the problem/task statement, problem situations, and the request from the parent project in the Real World. Then the problem should be analyzed to understand the present system and to understand the ideal system (Box 3). Such understanding should be done in various aspects including time and space characteristics, objects - attributes - functions, root causes, mechanisms, etc. The analysis can be guided by some problem solving method, but the information source must be the knowledge of the real problem and real situations. Getting images of the ideal system is also crucial at this stage for generating good solutions later.

Then in Box 4 various ideas for a new system are to be obtained. They are, exceeding simple hints in other systems for suggestion, some basic ideas, e.g., to change or introduce a core component/function for a new system. For generating these ideas various methods, such as check lists, hints, guidelines, principles, operators, etc. may be used. However, during the previous process of obtaining thorough understanding of the present and ideal systems, our brain usually work actively to think of various ideas smoothly. Thus a large number of ideas are to be listed and organized in a hierarchical system.

Around some core ideas, conceptual solutions (Box 5) should be constructed. In this stage, capability and knowledge in the subject matter are necessary even more than the methodological capability, in order to build up effective and creative conceptual solutions.

Conceptual solutions (Box 5) are the final results of the problem solving in the Thinking World, and yet just the start to implement into real products/services/processes in the Real World. For the implementation, various processes such as prototyping, secondary problem solving, experiments, CAE, designing, manufacturing, marketing, etc. are necessary and should be carried out with the full power of the industry, etc.

3. Possibility of integrating diverse methods of creativity and innovation

3.1. Requirements of proliferation by the society

For us, those who have encountered TRIZ and realized its tremendous possibility, it has been an eager hope of establishing TRIZ further as an effective methodology for solving various problems creatively and proliferating it widely. The actual progress of proliferation of TRIZ, however, has been much slower and limited than our expectations. In 2012, I was drawing the expected fields and themes of TRIZ applications, e.g., in industries, in government and public sectors, in academia and universities, in education, at home, in society, in mass media, etc. Then I realized that the people in all these areas of application do not want individual methods like TRIZ; they really demand some general methodology for creative problem solving applicable and effective in various areas. It should be a general methodology to be established newly at a level or two higher in the hierarchy of methodologies. I named the target methodology as CrePS (General methodology of creative problem solving/task achieving) [7].

The new target/vision is stated as [7]:

“To establish a general methodology of creative problem-solving / task-achieving, to spread it widely, and to apply it to problem-solving and task-achieving jobs in various domains in the whole country (and the world)”

3.2. Classifying various approaches of component methods

As a preparation for integrating such diverse and big methods, we should better decompose them into their component methods and classify them according to their types of approaches and intentions. A preliminary table of such component methods is shown in the following [7].

It is noticed that big methods are composed of various sub-methods and those sub-methods are largely overlapped with one another having some differences in detail and that many methods have their emphases in some aspects in this table and often intend to make shortcuts in the problem solving process. The current situations of the methodologies for creative problem solving (including creativity and innovation methodologies) are apparently unorganized and unnecessarily competing with one another, thus failing in contributing well to the society.

![Table 1. Various methods for creative problem solving, decomposed and classified in their approaches [7]](image)

The main reason for the unorganized competing situations of such a divergence of methods and sub-methods, as shown in Table 1, is the defect/weakness of the conventional paradigm, i.e., the Four-Box Scheme in science and technology in general, including TRIZ.
Introduction of the Six-Box Scheme as the new paradigm of creative problem solving (CrePS) will certainly serve for reorganizing these diverse methodologies and their numerous sub-methods [7].

3.3. Positioning the Six-Box Scheme in the Real World

The Six-Box Scheme (Fig. 1) says that the process of actual problem solving should start and finish in the Real World which contains the problem. We meet various problems and we want to solve them in the real situations, which differ widely in case by case. It is not theoretically sound if we assume such real situations belong to individually-specific Real Worlds. We should rather think of a number of different types of Real World corresponding to the areas where we want to apply. For example, in the case of industrial applications, we should consider a Real World where typical industrial activities are taking place, as shown in Fig. 2 [10].

It is important that the problem solving process (Box 2 through Box 5) in the Thinking World is more universal and less dependent on the problem types in the Real World. The USIT process, as illustrated in detail in the next section, is a concise process for such a general purpose problem solving in the Thinking World.

The step of solution implementation (from Box 5 to Box 6) should be carried out again in the Real World (of industrial application in the present case), and need to be adjusted well to different types of problems and solutions.

4. The USIT process -- its overview

The overall process of USIT is illustrated in Fig. 3 [7, 8].

Fig. 3. Overall process of USIT. Basic concepts of the six boxes, main information in each box, and processing steps. [7]

The left column in Fig. 3 shows the six boxes along the main stream of the Six-Box Scheme, while the middle column describes the main information to be obtained in each box in the USIT process. The right column lists the processing steps and their main methods used in USIT. It should be noted that the information in the boxes and the methods in steps are typically used in their standard USIT ways for various types of problems, while allowing minor adaptation to the problems [8].

The concepts and applications of the Six-Box Scheme (in the forms of TRIZ-extended, USIT, CrePS, etc.) have been publicly presented at conferences and posted in Web sites, especially in “TRIZ Home Page in Japan” [11]. Recently, the present author posted a full set of documents of CrePS/USIT in [12], including CrePS/USIT references, USIT manual, USIT case studies, USIT operators, etc. The USIT process is now described in detail in the USIT Manual [8] with the illustration of one case study consistently, and its usage is shown in more than 10 case studies documented in the consistent manner with the USIT Manual. In the next two sections the manual and the case studies are described.

5. USIT Case Studies described in the Six-Box Scheme

5.1. General intention of USIT Case Studies

As is described so far, we are now making efforts for integrating/unifying various creativity & innovation methods into a general methodology of creative problem solving (named CrePS) based on the Six-Box Scheme and for developing some easy and effective processes (e.g., the USIT process for a general purpose) of practicing the methodology. And we want to show its actual usage as the case studies.

We have already published a number of examples of applying the USIT process originally. So we have revised them as USIT case studies in accordance with the process and style of the USIT Manual.

Besides our own works, there are many more excellent case studies of solving problems creatively by use of TRIZ and other methods and published in various places. They
are good resources for showing case studies of the general methodology CrePS and its process USIT, I believe, if we review and restructure them in the paradigm of the Six-Box Scheme. So I started to select some case studies which are published by other authors applying different methods, and to review and rewrite them in the form of the USIT Case Studies. This work of rewriting case studies of different methods into the USIT Case Study in the Six Box Scheme is found productive for understanding various methods and for integrating/unifying such methods.

5.2. A Collection of USIT Case Studies

Fig. 4 lists the ten USIT Case Studies described so far both in Japanese and in English [9]. Each case study describes, in about 20 slides, the full procedure of USIT in accordance with the USIT Manual. You can read these case studies in its full length in the Web site, “TRIZ Home Page in Japan” [11].

<table>
<thead>
<tr>
<th>USIT Case Studies (In accordance with the USIT Manual)</th>
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<tbody>
<tr>
<td>1. How to fix a string shorter than the needle</td>
</tr>
<tr>
<td>2. How to prevent a staple from being crushed</td>
</tr>
<tr>
<td>3. Saving Water for a Toilet System</td>
</tr>
<tr>
<td>4. Picture Hanging Kit Problem</td>
</tr>
<tr>
<td>5. Increase the Foam Rate of Perso Polymer Sheet</td>
</tr>
<tr>
<td>6. A Mom’s Bicycle for Safely Carrying Two Children</td>
</tr>
<tr>
<td>7. How to Prevent Unauthorized Persons from Entering the Auto-locking Door of Apartment Building</td>
</tr>
<tr>
<td>8. A System for Preventing from Our Leaving Things Behind</td>
</tr>
<tr>
<td>9. How to Prevent Cards and Cables from Getting Entangled</td>
</tr>
<tr>
<td>10. A Large Variety of Writing Instruments: Studying the Evolution of Technologies</td>
</tr>
</tbody>
</table>

Fig. 4. 10 USIT Case Studies described in accordance to the USIT Manual

5.3. USIT Case Study 1. How to fix a string shorter than the needle

This case study is based on a thesis work by Tsubasa Shimoda at Osaka Gakuin University applying the USIT standard procedure to a familiar problem. For saving the space of the present paper, only the overview summary slide is shown in Fig. 5. The information obtained in each box is briefly shown with some illustrative sketches.

6. USIT Manual describing the USIT process in detail

When I explain about the Six-Box Scheme (Fig. 1) and the USIT process (Fig. 6), people often ask questions about how the idea generation step (i.e., from Box 3 to Box 4 in Fig. 1) is supported in USIT. Thus, for the purpose of illustrating the USIT process, two pages of the USIT Manual in the Idea Generation step are shown in the next page.

Fig. 7 shows the second sub-step of Idea Generation in USIT. For the purpose of generating more ideas systematically, the USIT process has the system of USIT Operators, which were developed by the reorganization/unification of all the TRIZ solution methods. For details of the operator system and its usage please refer to our paper [4] and documents [12]. Fig. 7 shows the instructions about the USIT Operators and their usage with illustrations.

USIT Operators are more systematized and easier to apply than 40 Inventive Principles, 76 Standard Solutions, etc. in TRIZ. However, if you are well familiar already with such TRIZ principles and solutions, you can of course use them at this sub-step in place of the USIT Operators.
Fig. 6. Instructions for the Idea generation stage (1) Spontaneous idea generation based on the understanding of the problem

Fig. 7. Instructions for the Idea generation stage (2) Extended idea generation by use of USIT Operators
7. Concluding Remarks

The present paper proposes to build a General Methodology of Creative Problem Solving (CrePS), for fulling the basic demand of creative ways of thinking, by integrating and unifying a large variety of methods and sub-methods developed so far in the world. The Six-Box Scheme is proposed as the new paradigm of CrePS for the integration. The USIT process is demonstrated as a concise and practical process for executing the Six-Box Scheme.

For further development of the CrePS methodology, we need to pursue the following aims and tasks:

- Case studies of applying various methods of creativity & innovation to different types of real problems should be collected, examined, and documented systematically to form the basis of developing CrePS and its processes.
- Activities in various types of Real World (such as shown in Fig. 2) should be examined and categorized in the aspect of creative problem solving, and suitable processes of creative problem solving in the Thinking World should be developed in accordance to the Six-Box Scheme.

Collaboration with you, researchers and promoters of different methods of creativity & innovation, is indispensable for establishing a general methodology proposed here. I should heartily appreciate your understanding and collaboration.

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Driving Growth Through Innovation at Reliance Industries

Dr. Michael Ohler*1, Naresh Shahani2, Sushil Borde3

1Innovation Leader, BMGI Europe, Buchsbaumweg 6, D-22880 Wedel, Germany
2General Manager, BMGI India, 905/906 Raheja Chambers, Nariman Point, Mumbai 400021, India
3Vice President, Reliance Innovation Leadership Centre, Reliance Industries Ltd., Maker Chambers - IV, Nariman Point, Mumbai 400 021, India

* Corresponding author. Tel.: +49 151 28415103; fax: +1 303-827-0011. E-mail address: Michael.Ohler@BMGI.com

Abstract

Our case study presents a view “behind the curtains” on how Reliance Industries, a major Indian conglomerate, has deployed a frontend innovation program in their organization. Key success factors are an ecosystem conducive to innovation, a high-profile innovation council, strong sponsorship from a dedicated leadership team and enabled and coached innovation leaders with a clear mandate to drive the innovation portfolio. This commitment to systematic and reproducible frontend innovation is paired with the ability to follow through in a structured way during the “backend” commercial exploitation of the resulting innovations. The goal is to “democratize” innovation throughout the organization.

The article shares details on the organization’s innovation governance, starting with how a large group of stakeholders in this multi-business organization was persuaded to adopt a common approach and how innovation leaders were selected to lead the efforts. It is laid out how a systematic approach for managing frontend innovation, integrated with TRIZ and other methodologies, is employed in this program. A portfolio of 24 such front-end innovation projects was scoped out of a strategy-driven pipeline of opportunities and then facilitated towards success in parallel and over the course of one quarter.

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Keywords: TRIZ; Innovation; Innovation Management; Innovation Governance; Structured Innovation; Idea Generation; Idea Management; Leadership; Methodology; Technology; Coaching; D4; Problem Solving; Team-Based Problem Solving; Reliance Industries
1. Purpose of the Article: Learning About Large-scale Innovation Programs

It is generally recognized that governance [1], project execution [2, 3], the distinction between frontend innovation (from recognizing an unmet need to a successful prototype) and backend exploitation (commercialization of the prototype) as well as a systematic approach to innovation projects [4] significantly enhance the odds of success for companies’ innovation programs. However, the confidential nature of these endeavors usually limits the practitioners’ ability to share much information around the “how to”. Our case study allows for a detailed view “behind the curtains” of a cross-industry innovation program inside the Indian conglomerate Reliance Industries. This initiative has the stated goal to “democratize innovation” and to grow future leaders for the company.

As innovation leaders in comparable organizations will confirm, convincing all stakeholders to subscribe to one common approach, to set up a governance and execution system and to manage a broad portfolio of innovation projects according to a given framework is no small challenge.

In the current case, for managing individual innovation projects, a frontend innovation framework, integrated with TRIZ and other systematic methodologies [4] has been adopted by the company’s innovation council and was welcome by the innovation leaders in charge of managing the projects.

2. The Reliance Growth Story

It is innovation that transformed Reliance from a small textile trading firm into India’s largest private sector enterprise and a Fortune 500 company. From sparking off the equity cult in India to setting up the world’s largest grassroots refinery to now ushering in a digital revolution in India through its 4G business, Reliance has demonstrated that innovation is in its DNA. Reliance’s innovations touch many facets of life in India, be it transportation, retail or healthcare.

With over 100,000 employees and USD $67 billion of combined annual revenue in 2014, Reliance Industries [5] counts among the largest Asian business players. Having grown over decades first within the polyester and textile industries inside India, operations now span across refining, oil exploration, petrochemicals, telecommunications and retail. The organization has been publicly listed since 1977 and has also been growing into Europe and the Americas.

Reliance’s growth model is mainly organic. With a mission to create wealth for all Indians, Reliance’s leadership team prides itself in having adopted “the long view.” The corporation has strategy-backed ambitions of becoming a Fortune 50 company.

3. Driving Innovation-led Exponential Growth at Reliance

The leadership at Reliance maintains emphasis on driving innovation-led organic growth, which is evident in the company’s unique innovation ecosystem. Innovation at Reliance focuses on the entire ecosystem surrounding business innovation—people, processes, technologies, structures and systems—to find innovation gaps and opportunities.

A vital part of this ecosystem is the Reliance Innovation Council, which was established to actively nurture innovation within the company. The council provides vision to the innovation movement at Reliance and is chaired by Dr. R. A. Mashelkar, one of India’s iconic science leaders. Other members of the council include Mr. Mukesh Ambani, Chairman and Managing Director of Reliance; two Nobel laureates and other internationally known innovation thought leaders [6].

For sustained growth across various industries at Reliance, excellence in the execution of innovation and relentless improvement are key elements of the company’s success formula. Therefore, leadership and innovation at Reliance are intimately connected, as is evident from the prestigious council’s focused mandate. One of the major successes to come out of the council’s vision is the Reliance Technology Group, which leads technology development at Reliance, and houses a state-of-the-art R&D centre.

Another element of the innovation ecosystem at Reliance is the Reliance Innovation Leadership Centre, which was set up to serve the innovation vision of the council. This centre implements the innovation agenda by deploying the best and next transformational innovative practices within Reliance. The Centre aims to impact every element of the innovation ecosystem at Reliance, be it people or processes, technologies or new businesses.
4. Designing an Innovation Initiative

In 2012, the Centre decided to implement a rigorous, reliable and predictable innovation process, which is directly connected to the organization’s leadership development program. The stated goal was to democratize innovation within the organization. To achieve that goal, Reliance planned to develop 100 leaders, versed in successfully conducting innovation initiatives, and turn them into innovation champions for further breakthrough innovation.

The program provides practical experience in global best practices in the discipline of innovation such as customer and user observation, need identification, rapid solution concept development and iterative prototyping. Such practices lead to breakthroughs in product and service development, operational efficiency, customer satisfaction and administrative effectiveness. In doing so, it will help instill an innovation culture in future company leaders.

Essentially, the program allows the project team—consisting of the Innovation Leadership Centre and external innovation experts—to identify potential leaders at Reliance and take them through the most relevant techniques on how to innovate. A key element was the emphasis that these future leaders apply the learned methods on real challenges that they will take on in their work.

4. The Reliance Innovation Leadership Program

This program evolved into what is now called the “Beyonders”, which aims at creating innovation leaders at Reliance by linking opportunity identification with innovation training (Figure 1). Participants learn multiple innovation approaches to break psychological inertia and enhance quantity and quality of their teams’ ideas. The program also equips participants with what it takes to lead substantial innovation projects. The logo of someone pole-vaulting reflects the attitude of Beyonders: Where others are satisfied with leapfrogging, Beyonders believe in pole-vaulting.

4.1. Opportunity Identification

In October 2012, Reliance partnered with outside innovation consultants in order to shape and execute the company’s ambitious innovation vision. The consultants provided a framework to select innovation leaders along criteria such as competencies, industry experience and past leadership experience. These leaders could be no more than two levels below the operating business heads of their respective business verticals within Reliance.

For a pilot run, 29 leaders were selected out of the organization’s diverse businesses. In a two-day intensive “innovation boot camp”, these leaders were introduced to the fundamentals and challenges of innovation, and the framework Reliance had adopted for frontend innovation [4]. The boot camp also offered deeper dives into concepts and approaches such as the Job to Be Done, Blue Ocean Theory, the Theory of Inventive Problem Solving (TRIZ), Ideality, Ideal Final Results, Functional Analysis, Resource Analysis, Nine Screens and ethnographic methods. The goal was to enable these leaders to identify customer needs, formulate them in a solution-neutral language and scope business opportunities around them. Given the importance of acknowledging and bringing to best use the full range of people’s problem solving styles, they were also introduced to the Kirton Adaption-Innovation Theory [7] and how to develop diverse teams and then manage creative diversity.

Ownership mindset and speed of execution are considered key leadership behaviors at Reliance. Upon completion of the opportunity identification workshop, participants were encouraged by the Innovation Centre to use their newly acquired knowledge and identify three innovation opportunities within a month. These opportunities were then presented to the respective business leaders and to the Innovation Centre. That led to the selection of one opportunity per innovation leader.

Upon the start of the program, 24 innovation projects were conducted by as many leaders. Innovation consultants supported these teams through the on-site facilitation of three consecutive workshops. Where required, coaching and on-site support were provided. The consultants also conducted independent research, in-depth TRIZ (e.g. solving contradictions or developing a Substance-field model) and technology investigations and back-office support. The Innovation Centre’s stated expectation was that high quality and predictability in the employed innovation methods be guaranteed to assure a high-quality outcome. The consultants also reviewed documentations and coached innovation leaders on their presentations to the Innovation Centre and to other business leaders.

4.2. Designing Rapid Innovation Cycles

It was the Innovation Centre’s clear requirement to conduct a fast-paced initiative. Within a quarter, solution concepts were expected to materialize for each of the innovation
opportunities. The Centre approved a project execution model that employed Rapid Innovation Cycles which build upon the frontend innovation framework shown in Figure 2. More details are provided and the links to TRIZ and other methods are established in another paper [4].

The Rapid Innovation model distinguishes between four phases: DEFINE the innovation opportunity, then DISCOVER a broad range of possible solution concepts, which are then used to DEVELOP a “paper or plastic” prototype which the team later DEMONSTRATEs can be turned fully functional. In this approach, the identification of the innovation opportunity, the frontend innovation project to address it and commercial backend exploitation are clearly distinguished.

Using this model for all innovation projects, the Rapid Innovation Cycles were structured by three three-day workshops for each of the first three phases: DEFINE, DISCOVER and DEVELOP (see Figure 3). During these workshops, where possible, three teams worked in parallel in the same conference room. Two consecutive workshops were typically separated by a month of intense and often coached teamwork.

The workshops were also set up in a way to foster cross-pollination between the three participating teams. For example, in a given session one team could be asked to perform a resource analysis for the challenge formulated by another team, who then conducted a functional analysis for the third who in turn predicted trends for the system the first team was investigating. Not least, the fact that the teams worked just a few meters apart, allowed for one team’s solutions to eventually turn into a good source of inspiration for the others.

Contrary to concerns initially raised by some participants in the program, innovation projects from different businesses could indeed be conducted in parallel across the first three phases of the frontend innovation framework as shown in Figure 2. This also contributed to the confidence the teams gained in applying the chosen approach for conducting frontend innovation projects in general.

Given the diverse nature of businesses and solution prototypes, projects diverged during their DEMONSTRATE phases. For example, the new setup of the check-out area in a supermarket was conducted differently than the introduction of a new petrochemical process. Therefore, it was not a requirement for the three teams that had previously worked in sync to come together to a common location also for a DEMONSTRATE workshop.

For the Innovation Centre, the predictable unfolding of the innovation initiative through workshops and intermittent team work helped it stay in full control throughout the innovation journey. The deliverables for each of the four phases of the Rapid Innovation Cycles also ensured teams stayed focused and helped management ask the right questions at the right time.

About at the middle of the journey, presentations were delivered to the Innovation Centre. For the closing ceremony of the DEVELOP workshop, “paper” or “plastic” (i.e.: often non-functional) prototype solutions were presented to business leaders in order to seek their approval to proceed into the DEMONSTRATE phases. These presentations included a mid-term implementation and a long-term business plan. Essentially, this extended the responsibility of the innovation leaders into planning the commercial exploitation phases of their innovation projects (“backend innovation”).

Commercial exploitation of innovation projects often involves conducting a number of interlinked projects. It has proved important to identify the nature of these projects and to conduct them according to the right methodology. For example, when a complex but known solution needed to be built, then classical project management methods were applied. For some of the innovation initiatives, existing processes needed to be made more capable, for which Lean Six Sigma improvement projects were set up. Other initiatives employed Design for Six Sigma projects to make sure a new design addressed many requirements in a first-time-right way. In the commercial exploitation phase of the innovation initiative, as with earlier phases, a controllable and predictable way forward was key to the overall success.

To that end, during the DEMONSTRATE and throughout the backend innovation phases of the projects, the Innovation Centre continued to exercise oversight over the entire initiative. Together with the innovation consultants, Reliance held another workshop with all teams. This workshop focused on distilling and disseminating critical success factors and to extract lessons learned throughout the initiative. The workshop also covered setting up the governance for the commercial exploitation, which by its very nature involved the broader organization. That was welcome as it presented another opportunity for democratizing innovation inside Reliance Industries.

4.3. How Rapid Innovation Cycles Were Set Up And Conducted

The Rapid Innovation Cycle workshops hosted three innovation projects in parallel in one room. In order to
respond to Reliance’s fast pace, four such waves, with three projects each, were conducted in the first week and another four waves in the second week of each month. Additional opportunities for cross-team exchange were built in by choosing the same location to conduct these four parallel waves of projects. The resulting additional organizational complexity was deemed to have shown the expected pay-off.

Fig. 3. How the three Rapid Innovation Cycle workshops, the teamwork and presentations to the Innovation Centre and to business leaders were organized. A total of 21 out of 24 innovation projects were approved to proceed into the DEMONSTRATE and commercial exploitation phases.

Setting up the entire initiative in this way also helped the facilitators focus on workshops during the first two weeks in a month and then dedicate their time to project coaching and research support during the other two weeks.

One of the challenges often seen in these and other innovation initiatives is that project teams can err on one of two sides: Depending on the team’s creative styles, ideas generated in the DISCOVER workshop can tend to be too radical or not radical enough. As a result, teams then either overlook exploitation of useful properties of the current businesses or they under-appreciate signals challenging the status quo. From the perspective of creative styles, this tendency can be well-understood in the frame of the Kirton Adaption-Innovation Theory [7].

Another common tendency is to protect the current way of conducting the business. For this reason, Reliance’s teams were requested to present “edge of the circle” ideas in their DISCOVER report-outs and to follow through on some of these ideas into the DEVELOP phase, the results of which were required to be reported.

As part of the overall innovation governance, leadership and top management of Reliance are hands-on involved in the execution of innovation projects. Management presentations to the Innovation Centre and to business leaders are also considered of critical importance for successfully driving change. To support the innovation leaders, the consultants provided templates, examples from other industries, best practices from other Reliance teams and further guidance. With their presentations, innovation leaders gained exposure and recognition in front of the Innovation Centre, their own business leaders and peers, as well as other business stakeholders, all of which turned out to help them lead the change associated with their innovation projects.

4.4. Maximizing Expert Engagement with Clients

With large and fast-paced initiatives such as the one conducted at Reliance Industries, external consultants have high impact but little margin for error. A rigorous approach and trust to follow it are required to keep participants and their projects on track and mutually aligned. Thanks to the very nature of facilitators attracted by such roles, innovation facilitators often have their own ways of getting things done. For an initiative such as the one described here, however, these approaches need to be made consistent and predictable through a senior engagement leader.

In the case study described here, the following additional approaches were taken to assure coherence between the team of consultants. First, for each wave two facilitators were paired for their entire duration. These pairs were built such that a range of perspectives could be provided to their client teams, like the views of an industry insider paired with those of an outsider, or an experienced TRIZ practitioner paired with someone versed in ethnographic methods.

Further, working with the Reliance team required all facilitators to have gone through a reading-diet and through intensive internal trainings that were conducted throughout the duration of the program. Each consultant was also expected to develop a deep understanding and to display expertise in at least one additional innovation approach he or she was previously not proficient in. These could include scenario planning, the lead user concept, ethnography, trend analysis, function analysis, Blue Ocean Strategy and a wealth of other approaches.

Right from the beginning, the facilitators were also exposed to the client leadership team and were requested to deliver presentations and trainings. Given that each client project was assigned one pair of experts, they could deep dive and develop subject matter and further industry expertise, to be paired with their general innovation methodology expertise. This approach also strengthened the facilitators’ sense of ownership for the success of their respective client projects. As a result of this approach, the consultants were well-accepted by the client teams and by the Innovation
Centre. They also gained the privilege of short communication loops with relevant client stakeholders and, not least, earned the teams’ respect and trust.

During the Rapid Innovation Cycle workshops, the facilitators also met face-to-face every evening in order to debrief with a senior engagement leader and to share success stories and lessons learned, to address any issues and to set the scene for the following day.

In the days between the workshops, the facilitators followed up with their respective client teams on-site and remotely in order to provide coaching and support. The goal was not only to secure successful project work but also to create momentum, a key factor for successfully anchoring innovation in the broader organization. To that effect, the role of business and innovation project leaders was to set the groundwork for involving more of their senior management team members and to prepare them for future work in similar innovation endeavors.

5. The Results of the Pilot Phase of Innovation

The majority of the projects (21 out of 24) were approved by the Innovation Centre and by business leaders as sound and aligned with the overall business strategy. Across all these projects, the confirmed business benefit was estimated to be well over USD $100 million of potential business contribution.

Several of the ideas that emerged and were piloted are expected to further benefit future expansion and replication projects of a similar nature within the company. Projects in the high growth business of retail have also led to large-scale projects of a similar nature within the company. Projects in manufacturing and business sites to work on innovation projects of a smaller scope. This new initiative is being championed at each location. In the first six locations, there are more than 150 projects underway in mid-year 2015.

6. Typical Methods Employed in Innovation Projects

Other than reporting here on the overall approach to govern the innovation initiative and to steer the portfolio of projects, we can also provide details on how selected innovation challenges were addressed. As any innovation practitioner will understand, the teams defined their challenges with a number of approaches and then used a range of different tools to discover potential solution concepts from which they developed promising prototypes. The following table provides further details on some of the approaches that contributed to gaining insights which in the end turned projects successful.

<table>
<thead>
<tr>
<th>Method</th>
<th>Successful approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Optimization</td>
<td>Use mechanical separation, coalescers and automated draining to extract water from a compound liquid.</td>
</tr>
<tr>
<td>SCAMPER</td>
<td>Modify (“M” in SCAMPER) the loading procedure of crude oil into a reactor in order to significantly improve the subsequent processing.</td>
</tr>
<tr>
<td>Provocation and Movement</td>
<td>TFG: Non-scheduled operators must pay in cash. Provocation: Non-scheduled operators pay with any means and in any currency.</td>
</tr>
<tr>
<td>Function Analysis</td>
<td>Out of 66 possibilities to “separate liquids”, acoustic cavitation and oxidation are selected as most promising to fraction a complex liquid into key components.</td>
</tr>
<tr>
<td>Separation Principles</td>
<td>Make a chemical reaction faster by increasing the temperature without impacting the yield of the reaction due to homogeneities: improve speed (parameter 9) without losing substance (parameter 23) leads to the use of “strong oxidants” (principle 38) in the form of weakly ferro-magnetic Cobalt to transfer heat from an alternating magnetic field to the chemical.</td>
</tr>
<tr>
<td>Substance-Field-Analysis</td>
<td>Do not use a field (heat) but use a substance (membranes) instead in order to distill out certain components of crude oil.</td>
</tr>
</tbody>
</table>

Table 1. Selected typical DISCOVER methods applied across different innovation projects in the portfolio. For these and other methods refer to [8].
7. Adapting the Innovation Framework to Existing Expertise in the Organization

Reliance Industries, like many organizations eager to boost organic growth and innovation, was looking for a predictable and replicable method that could be learned and then rolled out to the larger organization. Speed was a key requirement.

Few organizations start such an innovation journey from zero. Also at Reliance, this new initiative needed to offer a home to existing pockets of expertise in the company—and fit within the framework chosen for this innovation initiative.

For example, different parts of the organization had already used methods such as design thinking, outcome driven innovation, Blue Ocean Strategy, TRIZ and others. Therefore, some flexibility was needed in order to bring to best use such existing expertise or preference. To that effect, innovation leaders and facilitators enjoyed ample freedom as long as the projects followed the agreed-upon frontend innovation approach and produced the required deliverables. This setup is thought to have contributed to the overall acceptance of the initiative.

Further, the leadership development program “Beyonders” was initiated with the aim of creating innovation leaders in order to drive rapid, innovation-led, organic growth for Reliance. The company is convinced that the development of future leaders includes making them well-versed in systematic innovation. The role of these leaders is to then champion the cause of growth through innovation across Reliance, taking the company one step closer to establishing a dynamic culture of innovation.

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Abstract

This paper investigates the integration of several innovation techniques with TRIZ techniques to manage Front End Innovation projects. The research culminated in a framework that integrates many innovation oriented techniques along with TRIZ concepts and techniques. Most of the traditional innovation processes often fail to manage the complex and uncertain environment of most radical innovation projects involving high assumptions and low knowledge. Early results show that the addition of TRIZ techniques can increase the success rates of these projects. The framework integrates techniques such as Job-To-Be-Done, Outcome Expectations, Ethnography, Design Thinking, Lateral Thinking techniques, Biomimicry, Axiomatic Design, and Rapid Prototyping.

The framework is the result of several years of Front End and Back End Innovation projects carried out within a number of organizations. The Front End framework consists of four phases: define the (solution-neutral) innovation opportunities, discover new ideas to satisfy unmet needs, develop solution design based on ideas and demonstrate the innovation. TRIZ techniques are integrated into each of the phases. The integration and application of the framework is discussed with the help of a case study example.

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Keywords: Innovation Management; TRIZ integration; Front End Innovation Techniques; Design Thinking, Rapid Innovation Cycle

1. Introduction

Creative destruction, a term coined by the Austrian economist Joseph Schumpeter [1], is taking its toll on corporations. Executives report an accelerating pace of change in an increasingly competitive business environment driven by globalization, changes in market trends, customer demands, regulations and lower barriers of entry [2, 3]. To address these changes, companies must find new forms of differentiation by better managing their internal processes, as well creating new solutions and services. Companies must earn their place in the market every day by becoming more agile, more innovative, and more adaptable. Innovation is recognized in academic and industry sectors as a key enabler for competitiveness and growth of any enterprise [4, 5].

However, researchers report that most innovations fail. Bhide [6] showed from a study of new ventures from over 400 entrepreneurs that over half of these failed. Of those that succeeded, 93% reported that the strategy that helped them succeed was considerably different from the innovation strategy they conceived at the outset. Others report that 75% of products established companies introduce to the market place fail to produce viable, profitable results. The problem emanates mainly from the management of the innovation process, starting with identifying unmet customer needs and ending with commercialization or implementation [7, 8, 9].

A well-defined and managed innovation process should serve as the backbone of any enterprise interested in creating and sustaining differentiation and competitive advantage. The innovation process has evolved over the years into many generations. Separating the exploratory nature of the innovation process from the systematic design and development process of products and services has shown to improve the quality and efficiency of the innovation process [10, 11]. The exploratory process, hereafter called “Front End of Innovation” differs from the typical product design and development process, hereafter called the “Back End of Innovation” in many ways. The Front End of Innovation has...
to handle many uncertain aspects about customer needs, feasibility and viability of solution concepts and adoption by customers. The Back End of Innovation, on the other hand, requires a very thorough and systematic way of designing a proven and promising concept that cannot afford to fail when launched first time.

The Theory of Inventive Problem Solving (TRIZ) has been effectively used during various stages of innovation. It has a set of robust techniques and methods for analyzing problems; identify contradictions; analyzing insufficient, harmful and excessive functions; and offering clever solutions from past designs from related or unrelated industries. However, there is an opportunity to link TRIZ techniques and tools with techniques and tools from other domains typically used within Front End Innovation frameworks.

The aim of this paper is to illustrate a framework for Front End Innovation and show how TRIZ techniques and tools can be effectively integrated to increase the odds of success during exploration of opportunities, idea generation and early prototyping. The framework has been utilized by the authors and others in a number of innovation projects, and has shown success by the measures determined by customers and providers in a variety of industries. The paper will present some ideas and concepts on how to implement such a process using a case example with the objective of how to improve the innovation capability of an organization.

2. Front and back end process for innovation

Many researchers and practitioners have discussed at length the poor track records of innovations [12,13,14], and the evolution of innovation process models in many generations [15]. Early generations of innovation process models use a linear flow and structure with the focus on pull from the market or push by the technology innovations. The later linear flow of Stage-Gate model is depicted in Figure 1.

![Fig. 1. Stage-Gate model for product development [16]](image)

During the late 1990s and early 2000s the Stage-Gate model became popular within corporations as the model for product development. The model segments the product development process into stages of activities such as gathering customer needs, developing concepts, creating subsystems, developing detailed designs, and piloting or prototyping. The end of each stage is characterized by a tollgate that acts as decision point. During the cross-functional review of each gate, a decision is made to proceed, terminate or recycle. If the review was favorable satisfying the toll gate deliverables, the project is allowed to proceed to the next phase. If the review was not favorable, a decision is made to stop the project or send it back for more research or analysis.

While the Stage-Gate model offers a very thorough and rigorous process for product development, the linear and arduous nature of the model has been found to be limiting in nature during early phases of innovation activities involving assessment of customer needs and concept generation. Many innovation projects that require radical departure from the current paradigm require a flexible, iterative and learning-based process. The Stage-Gate model has been subsequently modified to address some of its limitations. Notable among them are the Collaborative Innovation model from United Technology [17] and Minnesota Innovation Research Model [18] and Open Innovation model [4]. More recently Du Preez et al [10,19] and others [11] have recommended separating the early phases of the innovation from the latter phases. Collectively, the early phases are typically known as “Front End of Innovation”, or “Fuzzy Front End” and the latter phases are known as “Back End of Innovation” or “Back End Design”.

The Front End of Innovation is characterized by identifying unmet needs of customers within a market segment, generating and selecting ideas, turning ideas into a workable design and turning the design into prototype and testing them. Due to the uncertainties associated with this process, it is an iterative process and must be flexible enough to evolve the precise opportunity and solutions. The process of Back End of Innovation is to take successful ideas from the Front End and perfect them. The emphasis during this process is “Design for X”, where X stands for objectives such as Manufacturability and Assembly, Sustainability, Reliability, Robustness, Durability, Maintenance, and Cost. This process in general is linear and can consume considerable resources and time.

As described above, the Front End of Innovation requires a process with flexibility, speed, iteration, and low cost. This is because the assumptions about the customers, viability of ideas, design of solutions, adoption rate of solutions and implementation details are very high during this process. In other words, the assumption-to-knowledge ratio during this part of the innovation journey is very high. Our objective is to identify and convert these assumptions and turn them into knowledge. Therefore, the emphasis is to learn fast and cheap through a series of experimentations as this process has to maneuver areas of uncertainty. One has to maintain the mind-
set of explorers to be successful during this process.

On the other hand, the Back End of Innovation is to perfect a promising idea so that the design when commercialized or implemented works flawlessly. The typical product development process known as New Product Development (NPD) works well for the Back End Design. A typical NPD process has many stages and gates. The stages usually consist of customer needs stage, concept design stage, preliminary design stage, detailed design stage, piloting and prototype testing stage, scale up and launch stage. The assumption-to-knowledge ratio during this process is usually low compared to the Front End Innovation. For this reason, the linear approach with emphasis on quality of deliverables improves the robustness of this process.

3. TRIZ and innovation

The Theory of Inventive Problem Solving (TRIZ) has been recognized as a key enabler for innovation, especially during the concept formulation phase. With the help of patent research, TRIZ researchers have identified several universal principles of creativity that served as the basis for advances in technology. These principles, as codified in the TRIZ body of knowledge, could be used by the practitioners to make the process of innovation more predictable and scalable.

The TRIZ body of knowledge contains a set of problem formulation and analysis techniques, including modeling and algorithmic techniques that enable the generation and resolution of novelty. The problem formulation techniques include Ideality, Ideal Final Results, Functional Analysis, Resource Analysis, Nine Screens, Substance-Field modeling, contradiction modeling, Many Little People (MLP) modeling and Subversion analysis. Algorithmic techniques include 40 Inventive Principles to resolve technical contradictions, Separation Principles to resolve physical contradictions, 76 Standard solutions to predict the potential evolutions of technologies, and Scientific Effects to conduct function-oriented search. In addition, an improved approach for inventive problem solving called ARIZ was created to tie together the application of TRIZ techniques in a step-by-step manner.

TRIZ continues to generate both interest and debate within the innovation and design community. Some researchers report promising improvements in performance by designers exposed to TRIZ [20, 21], while others explore the benefits and limitations of combining TRIZ with other design methods. These latter studies include the integration of TRIZ with Design for Manufacture and Assembly [22], Axiomatic Design [23], and Quality Function Deployment [24].

4. Front end of innovation and integration with TRIZ

Lately, the Front End Innovation process has received much attention as its effects downstream results. Many researchers [25,26] have shown that the greatest differences between innovation winners and losers were found in the quality of execution of the Front End Innovation process.

In the innovation literature, a variety of related terms are used to describe the front end of innovation. They include “fuzzy front end”, “pre-development”, and “concept development” [25]. In general, the front end ranges from identifying customer needs to the generation of an idea to demonstration with a prototype. During the front end of innovation, the degree of freedom in design choices and impact on project results are high, whereas costs for changes are low. This front-end advantage is limited by the fact that the amount and certainty of information is low or assumption-to-knowledge ratio is high compared to later stages of the innovation process. Hence, sound decisions cannot be made unless necessary information is gathered during the course of the innovation process. Many methods, techniques and tools such as Job-To-Be-Done, Outcome Driven Innovation framework, Ethnography, Lateral Thinking Techniques, Biomimicry, Axiomatic Design, and Rapid Prototyping techniques have been reported to successfully handle the challenges faced during the front end of innovation. We propose that by integrating these techniques and methods with TRIZ techniques and algorithms into a cohesive framework, one can reduce the market, technological, design and adoption uncertainties.

The key stages involved in the innovation and design process are discussed extensively in the literature [11, 27, 28, 29], so we will not review them here. Most front end innovation process models share a common understanding of these stages, which typically include some form of needs gathering, concept generation, detailed design, prototyping, and testing – although different terms may be used in each case. For our purposes here, we will use the simple four-stage model for design shown in Figure 2. Put simply: We first define the innovation opportunity, then discover ideas for addressing it, develop the details of the resulting design, and finally, demonstrate the solution.

These four stages have been broken down into sub-process steps to help describe what occurs in each stage in greater detail. Each stage of the design process is also associated with two fundamental cognitive operations, namely: divergent thinking and convergent thinking, which have their roots in problem solving research. The divergent thinking operation involves searching for ideas and increasing one’s options through elaboration of the design problem, redefinition of the problem, and by exploring, connecting, and/or combining potential ideas/solutions. In contrast, the convergent thinking operation involves evaluating ideas and narrowing or reducing one’s options through the imposition of value judgments, exploiting the information available about the ideas, prioritizing, and selecting.

Fig. 2. A simple four-stage model for front end innovation
Given this simple process flow, TRIZ techniques are integrated with other innovation techniques and classified according to the stage or step of the design process in which they are most usefully applied (Figure 3). For example, in the Define stage, an individual (or team) may frame the innovation opportunity using Ethnography, Job-To-Be-Done [14], and Outcome Expectation [30] techniques. Ideality and Ideal Final Result from TRIZ bolster the understanding of the opportunity whereas the Nine Windows technique can be used to reframe or scope the opportunity. Most of these techniques are focused on pinpointing the opportunities from the customers’ point of view.

The Discover stage involves analysis of the existing solution space, generation of ideas as well as selection and refinement of ideas. The analysis of the solution space is carried out with TRIZ techniques such as Functional Analysis, Resource Analysis, and Trend Analysis. Once the opportunity is clear from the customer needs perspective and strengths and weaknesses of the solution space are identified, one can begin to generate new ideas. Many brainstorming techniques and its variants such as Lateral Thinking techniques can be used to generate ideas that individuals and teams already have. Additionally TRIZ techniques such as 40 Principles, Separation Principles, Standard Solutions, and Function databases can help generate more ideas in a systematic and comprehensive manner. Biomimicry techniques can also aid in this process. Many of the TRIZ techniques can enable the generation of ideas from both within existing industry paradigms and outside of them. Idea generation is followed up with idea evaluation, prioritization and refinement. Several techniques such as KJ Method, Multi-voting and Impact versus Effort techniques can be used in this regard. Ideas are then further evaluated and refined using such techniques as Six Thinking Hats®, Idea Sorting and Refinement.

The Develop phase of the process is focused on systematic design using the ideas generated during the Discover phase described above. Systematic design starts with identifying useful and harmful functions associated with the proposed ideas. They are mapped against design parameters to establish the subsystem design. One can use design techniques such as Function Structure and Morphological Matrix to generate multiple design concepts. The concepts can then be evaluated and prioritized using techniques such as the Pugh Matrix or Analytical Hierarchy Process. The selected design is then improved and optimized using a variety of techniques. Subversion Analysis (Anticipatory Failure Determination) from TRIZ can be used to improve the design.

The Develop phase is then followed up with the Demonstrate phase in which prototypes are built and tested. A variety of methods such as Rapid Prototyping, and Design of Experiments can help generate options for testing, analysis and review. Root cause analysis techniques can be used to understand the underlying causes for system performance. When issues are detected, we can use TRIZ techniques to overcome conflicts, and improve performance. At the end of the Demonstrate phase, key decisions are made to determine the success of the project and if the project is deemed successful.

---

**Fig. 3. Integration of TRIZ techniques with front end innovation**

<table>
<thead>
<tr>
<th>Define</th>
<th>Create Innovation Opportunity</th>
<th>Jobs To Be Done</th>
<th>Outcome Expectations</th>
<th>Ideality/ Ideal Final Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scope Innovation Opportunity</td>
<td>Heuristic Redefinition</td>
<td>Nine Windows</td>
<td>Job Scoping</td>
</tr>
<tr>
<td></td>
<td>Manage People and Projects</td>
<td>Stakeholder Management</td>
<td>Cognitive Style</td>
<td>Project Charter</td>
</tr>
<tr>
<td></td>
<td>Refine Innovation Opportunity</td>
<td>Technology Trends</td>
<td>Resource Optimization</td>
<td>Functional Analysis</td>
</tr>
<tr>
<td></td>
<td>Leverage Team Brainpower</td>
<td>HIT Matrix</td>
<td>SCAMPER</td>
<td>Brainwriting 6-3-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concept Tree</td>
<td>Random Stimulus</td>
<td>Provocation and Movement</td>
</tr>
<tr>
<td></td>
<td>Prioritize and Select Ideas</td>
<td>KJ Method</td>
<td>Idea Harvesting and Treatment</td>
<td>Six Modes of Thinking</td>
</tr>
<tr>
<td></td>
<td>Formulate Design</td>
<td>Functional Requirements</td>
<td>Axiomatic Design</td>
<td>Function Structure</td>
</tr>
<tr>
<td></td>
<td>Select Design</td>
<td>Paired Comparison Analysis</td>
<td>Pugh Matrix</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optimize Design</td>
<td>Robust Design</td>
<td>Subversion Analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design Scorecard</td>
<td>Design FMEA</td>
<td>Discrete Event Simulations</td>
</tr>
<tr>
<td></td>
<td>Build A Working Model</td>
<td>Prototyping</td>
<td>Piloting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Map Processes</td>
<td>SIPOC</td>
<td>Process Map/ Value Stream Map</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optimize Processes</td>
<td>Measurement Systems Analysis</td>
<td>Process Capability</td>
<td>Work Cell Design</td>
</tr>
<tr>
<td></td>
<td>Improve and Transition</td>
<td>Control Charts</td>
<td>Cause &amp; Effect Analysis</td>
<td>Subversion Analysis</td>
</tr>
</tbody>
</table>
5. Case study

Over the past several years, we have tested the integrated framework on several Front End Innovation projects within a variety of industries with high success rates. However, due to the confidential nature of these projects, we are limited in our ability to discuss many of the details. The approach has been used with several product and service innovation, process innovation, and business model innovation projects.

This case study focuses on the Front End Innovation projects carried out within a financial services industry. The company operates within the banking and insurance related sectors. The focus of the work has been to understand the unmet or underserved needs of the customers who purchased banking and insurance related products from the company and find better ways to provide services to them.

The project was initially scoped for certain key segments of the customers. Four cross-functional teams were responsible for the execution of four projects conducted as a rapid innovation cycle. During the Define phase of the work, each team identified the job the customers were trying to get done, mapped out how customers were trying to get the job done, and captured their list of outcome expectations for how each job would get done. The initial part of the development was carried out with qualitative research tools such as ethnography and focus groups to develop the job maps and outcome expectations. A particular job map contained steps customers used to receive services. Examples of job steps included “update personal information”, “file a claim”, “pay bills”, “link savings, checking and retirement accounts”, and “receive a loan”. For each job step, there are multiple criteria (outcome expectations) customers used to determine success of failure of how the job step was getting done. For example, a job step such as “update personal information” produced multiple outcome expectations such as “minimize the effort it takes to update personal information”, “increase the likelihood that personal information can be updated using the channel (mobile app, website, call center, email, etc.) of preference”, and “increase the likelihood of receiving confirmation of the completed updates”. In TRIZ vernacular these outcome statements are synonymous with the ideality. Subsequently, quantitative techniques were used to prioritize these outcome statements by customers on importance and satisfaction dimensions. Items that the customers rated as high importance and low satisfaction were deemed as under-served opportunities for innovation. Survey techniques, sample size calculations, sampling strategies and other quantitative techniques such as factor analysis and cluster analysis provided assurance on the validity and reliability of the under-served outcome expectations grouped by customer segments. Difficult scenarios were analyzed with the Nine Windows (system operator) technique. This ended the Define phase of the work.

The Discover phase of the work started by utilizing several TRIZ techniques. Functional analysis, Resource Analysis and Trend mapping exercises enabled the team to understand the current state and opportunity for innovation. For each of the opportunity, the teams generated one or more Ideal Final Results. This formed the polar star for the innovation expedition. The team proceeded with various forms of brainstorming techniques to discover ideas on how to close the gap between current state and Ideal Final Result. A set of residual problems were left that could not be solved with various forms of brainstorming and lateral thinking techniques.

The residual problems were analyzed further to extract the insufficient functions, harmful functions and excessive functions. A contradiction analysis also revealed the technical contradictions and physical contradictions of hard-to-crack problems. TRIZ methods or techniques such as Function benchmarking, 40 Inventive Principles, Separation principles and Standard Solutions enabled cracking of the residual problems. For example, customers wanted to update their home address on bank records after relocating to a new home. They would like to do this in a timely manner, with low effort and with certainty. An Ideal Final Result is that the address is updated by itself after relocation without customer involvement. An idea that the team had was to use the relocation information available with the postal department database. However it creates a contradiction. The effort from the customer to update information is lowered but the perception of breach of privacy is increased. TRIZ techniques enabled the formulation of elegant solutions without compromise.

A total of over 1,400 ideas were generated during the diverge operation during the Discover phase. These ideas were organized, duplicated removed and affinitized for further processing. The affinitization created three levels of parent-child groupings of ideas. These higher level categories were called concepts. There were over 70 concepts that were then evaluated for impact on customers and providers as well as for the effort it would take to implement them. This method allowed the company to prioritize concepts that are great candidates for further design and development.

During the Develop phase of the process, teams selected 12 key concepts and created the design of the new processes to support the new services. Many design techniques such as Function Structure, Morphological Matrix and Axiomatic Design enabled the design of subsystems and processes. For one of the concepts, “gamification” was used to educate and help customers with deciding on choices for their retirement accounts. With the help of the techniques mentioned, teams created several choices for how gamification applications could be designed. During the design, many teams encountered contradictions, harmful functions and insufficient functions. TRIZ techniques were revisited to make progress and resolve the challenges. Competing design options were prioritized and selected using the Pugh Matrix and evaluated using the Six Thinking Hats approach. Designs were further improved using Subversion Analysis (Anticipatory Failure Determination), Design FMEA, Mistake Proofing principles, and simulations.

During the Demonstrate phase of the process, prototyping and testing of the concepts were carried out. Paper prototypes were used to get early feedback from customers on the solution concepts. Subsequently, wireframe prototypes and clickable prototypes allowed more detailed and thorough feedback from customers. Many assumptions made by teams
about the customer perceptions and behaviors turned out to be wrong. Based on the feedback, teams updated their designs and completed the Front End Innovation cycle.

The projects were subsequently reviewed by leadership in order to evaluate them for funding and resourcing against the company’s strategies. Most of the solutions became part of the portfolio of solutions and services implemented using their Product Development process (Back End process) to ensure that the services are launched in a timely manner with high quality and certainty.

6. Lessons learned and recommendations

The case study above illustrates how TRIZ techniques were integrated into a Front End Innovation framework with other tools and techniques from a broad set of marketing, idea generation, design and development, project management, and change management domains. We continue to use this framework within a variety of industries and companies with a great deal of success. Some of the lessons learned from our experience are listed below:

- Experience shows that the traditional linear stage-gate process used for new product development is not very efficient for the Front End innovation area.
- The success rate of innovation is largely governed by the quality of the innovation process.
- Ideas should not be the input to Front End of Innovation. It should be the response to the quantifiable and verified unmet or under-served needs of the customers.
- TRIZ techniques and methods, when integrated with techniques from other domains, can enhance the quality of Front End Innovation.
- TRIZ techniques can be used to supplement the various brainstorming methods or Biomimicry techniques.
- A holistic approach driven by cross-functional teams provides the breadth and level required of complex problem solving undertaken during Front End Innovation.

The maturity of innovation processes has evolved over many years. A network approach to the innovation process is important to increase the odds of success. Decoupling Front End and Back Innovation has shown promise in this direction. Further research should be carried out with academic and statistical rigor to show the informed hypothesis that the integration of TRIZ techniques into the Front End Innovation process enhances the odds of success.

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Redesign of a spray coating system for paperboards using TRIZ techniques

Philip Samuel*, Derek Bennington, Riaan Brits, Brian Miller

*BMGI, 1200 17th Street, Suite 180, Denver, CO 80202 USA
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Abstract

In the manufacture of paperboards, treating agents such as latex or starch based coatings are applied to enhance the functionality of paperboard. However, current methods used within the paper manufacturing industry are very inefficient or insufficient. For example, it is typical to use a roller based system to apply a coating agent onto semi-finished paperboard and then scrape off the excess coating with a doctor blade. However, a large percent of the excess coating removed is contaminated with fiber and cannot be fully reclaimed, resulting in poor yield.

This paper provides the details of a redesigned spray coating system with the help of TRIZ techniques. First, functional analysis was used to understand the interaction between system elements and to highlight missing, useful, excessive, insufficient and harmful functions. Second a contradiction analysis was performed to identify the technical and physical contradictions. Third, an ideal final result was formulated to find the polar star that guides the innovation. With the help of inventive principles and function oriented search using Scientific Effects database, new ideas for spray coatings were developed. However, an analysis of a patent database revealed several barriers due to existing patents. Patent circumvention strategies using TRIZ-based design-around approaches enabled the creation of new intellectual property for the redesign of a spray coating system.

1. Introduction

In the manufacture of paperboards, treating agents such as coatings are applied to enhance the functionality of paperboard [1]. The application of latex or starch based coating can enable the paperboard to be used for diverse packaging purposes, such as preserving dry goods (e.g., tobacco), protecting perishables (e.g. frozen food) and providing a sterile environment (e.g., medical tablets). The enhancement of functionalities are usually aimed at optical properties such as brightness, gloss or opacity, and mechanical properties such as foldability, tensile strength, smoothness, printability and print image quality [1,2,3]. Also, the application of white pigments to the base paper surface enhances the brightness of the paper. In addition, the high light scattering of the pigments enable an increase in opacity of the coated surface. This in turn improves the optical appearance, because the shine-through of the back side printing is reduced. Also, the coated layer improves the flat surface topography of the paperboard, resulting in an improved smoothness, which in turn provides a better gloss.

It is desirable for the surface of the coated paperboard, when used for packaging purposes, to have certain characteristics that enable high quality printing. The ink should not spread much and the print image must be clear and sharp. The coated layer reduces the penetration of ink into the paper sheet; as a result, the print density and the print gloss are enhanced, and the ink needed for printing is reduced compared to uncoated papers.
The benefits of applying a coating layer become very apparent when comparing paper surfaces with different coatings. Figure 1 is a Scanning Electron Microscope (SEM) image of the cross-sectional view of a coated paperboard. It shows the paper surface characterized by hills and dales formed by the fiber mesh. The voids between the fibers impair the smoothness and uniformity of the paper surface.

Two layers of coating are visible in the image. The first layer of coating, known as the base coat, is used to cover up the majority of voids and fibre crossings. This helps to smooth and even out the paper surface. Paper surface quality is further enhanced by the application of a top coat. Subsequent calendering achieves an additional quality gain by enhancing smoothness and gloss. The resulting surface is flat, with a minimum of irregularities.

A number of methods are used to form one or more layers of coating. Water-based coating agents are typically applied to semi-finished paperboard with the help of a roller based system [1]. Excess coating applied by the roller based system is scraped off by a doctor blade, or air knife, to control the coating weight and smoothness. Figure 2 illustrates the system with a doctor blade. Several applications may be applied and dried in one pass through the coating machine, giving a desirable total coating weight. However, a large percent of the excess coating removed is contaminated with fibre and cannot be fully reclaimed, resulting in poor yield. In addition, the doctor blade gets worn out after several hours of application and has to be replaced every few hours, resulting in lost productivity. Many attempts have been made to improve the situation by optimizing the existing system. This situation presented with an opportunity to redesign the system completely.

2. TRIZ as an enabler for concept design

Theory of Inventive Problem Solving (TRIZ) has been recognized as a key enabler for innovation, especially during the concept formulation phase. Early studies conducted by TRIZ researchers led to several general observations [4,5,6], which would become the basis for the TRIZ process and its supporting techniques:

- Problems and solutions were repeated across industries with some specific patterns.
- The evolution of engineering systems is not random, it follows a pattern.
- “Breakthrough solutions” used scientific effects outside the field in which they were originally developed.
- The strongest solutions were often the result of overcoming a contradiction (also known as a “system conflict”).

With the help of patent research, TRIZ researchers have identified several universal principles of creativity that served as the basis for advances in technology. These principles, as codified in the TRIZ body of knowledge, could be used by the practitioners to make the process of innovation more predictable and scalable. TRIZ body of knowledge contain a set of problem formulation and analysis techniques, including modelling techniques as well as algorithmic techniques that enable the generation and resolution of novelty. The problem formulation techniques include Ideality, Ideal Final results, Functional Analysis, Resource Analysis, Nine Screens, Substance-Field modelling, contradiction modelling, Many Little People (MLP) modelling and Subversion analysis. Algorithmic techniques include 40 Inventive Principles to resolve technical contradictions, Separation Principles to resolve physical contradictions, 76 Standard solutions, or versions of it, to improve missing, insufficient, harmful or excessive functions, Trends of Evolutions to predict the potential evolutions of technologies and Scientific Effects to conduct function-oriented search. In addition an improved approach for inventive problem solving called ARIZ (the Algorithm for Inventive Problem Solving) was created to tie together the application of TRIZ techniques in a step-by-step manner [7].

3. Redesign of spray coating system

Several TRIZ techniques were used to formulate and analyze the existing coating application system. Function analysis, Contradiction analysis, Ideal final result, Inventive principles, Function oriented search, and TRIZ inspired patent circumvention strategies were used to redesign the spray coating system. Function analysis revealed that the adhesion function of coating agent to the paperboard was insufficient. In the current method this insufficient function was compensated by excessive addition of the coating agent by the roller applicator and then unnecessary material removed by the doctor blade. However the excess coating scraped off by the doctor blade was contaminated by the fiber from the semi-finished paperboard. One of the Idea final results would be that precise amount of coating would adhere itself to the semi-finished paperboard so as to create the desired level of surface characteristics such as optical and mechanical properties. This would eliminate the need for applying excess coating or
removing unwanted coating back from the paperboard. Therefore one of the opportunities is to improve the adhesion function of the coating agent to the paperboard.

A technical contradiction analysis was carried out using Matrix 2003, a modified version of Altshuller’s original Contradiction Matrix by Mann et al [8]. The improving parameter for the inventive problem is the uniformity of the coating agents adhered to the surface of the semi-finished paperboard. The following list of potential surrogate parameters from Matrix 2003 was chosen to represent the improving parameter:

- 10 amount of substance
- 21 stability
- 39 Appearance
- 42 Manufacture Precision/Consistency
- 46 Control Complexity
- 48 Measurement Precision

Similarly the worsening parameter for the problem is the amount of substance wasted during the application. The following list of potential surrogate parameters from Matrix 2003 was chosen to represent the worsening parameter:

- 2 Weight of stationary object
- 8 Volume of stationary object
- 10 Amount of substance
- 25 Loss of substance

![Fig 3. Technical contradiction between potential conflicting parameters](image)

Figure 3 shows the results from Matrix 2003 in terms of the potential inventive solutions for combinations of the potential surrogate parameters. The main proposed solutions were Parameter Change (35), Composite Material (40), Another Dimension (17), Mechanics Solution (28), and Preliminary Action (10). Potential clues derived from these principles were to:

- alter the state of the coating agent or paperboard
- clever use of geometry and spatial application
- change the composition of coating agent or paperboard
- modify the field currently used from mechanical and chemical to others such as acoustic, thermal, electrical, magnetic, intermolecular and biological
- and conduct a certain preparatory action on the coating or paperboard surface before the application

Subsequently a function oriented search was performed. Function oriented search has been reported as an enabling technique within TRIZ when searching for new generation of solutions belong to TRIZ invention levels 4 and 5, which require dramatic changes in the design of a product or process [9]. The main idea of this approach is to find an existing technology from another industry and transfer it to the initial problem, as a solution. Thus, we can offer a new and very effective action principle to solve the initial innovation opportunity. A key benefit to this approach is to minimize the time required to prove the effectiveness of the scientific principle behind the technology as the technology has already been demonstrated in another industry. However, one still has to prove the precise implementation and embodiment of the technology to the initial problem.

A function oriented search was performed using CREAX Function database [10] as well as Oxford Creativity Effects database [11]. A search for “deposits liquid” from CREAX Function database revealed 11 principles since the key useful function is to deposit the coating agent that is a mixture of liquid and solids. Another search for “embeds solids” from CREAX Function database revealed 6 principles. The logic behind this search was embedment of solids into the uneven crevices of semi-finished paperboard. A similar search was conducted for the function “deposit liquid” using Oxford Creativity database producing 23 principles. These principles were further studied for its applications in other industries. They were then analysed and prioritized using several factors for feasibility, desirability and viability [12]. The key technologies chosen were spray nozzle application of the coating agent, preliminary action of applying electrostatic field to the coating agent and paperboard as well as ultrasonic pulsing of the coating agent.

A scanning of protected intellectual property was carried out against these feasible ideas. Infringement analysis of the relevant patents in the field showed a potential conflict with an existing patent. TRIZ based approach [13] was used to model the independent claims of this patent. Figure 4 shows the function model of the independent claims of the patent in question. Analysis consisted of determining whether or not the new solution may potentially infringe on the original patent and if so, device a circumvention strategy.

![Fig 4. Function model of the independent claims of the patent](image)

In order to circumvent an existing patent, the new design around solution must satisfy two important patent infringement rules. As discussed by Somaya [14], these two
rules as discussed below, check if the new patent would impinge on earlier patent claims.

- The all elements rule: this rule is applicable to all new patents, according to which each element of a new patent claim must be present in an allegedly infringing device (patent) in order to establish a literal infringement.
- The doctrine of equivalents: if the new patent makes a minor departure from the original patent claims and therefore, does not literally infringe the original patent, the new patent may nevertheless be held to be an infringer if the new patent (a) achieves substantially the same function, (b) in substantially the same way, and (c) to obtain substantially the same result.

Consistent with recommendations from various TRIZ researchers [13,15], we utilize the following design around strategies on the function model of independent claims in order to create new concepts that circumvent the infringement rules:

- take one or more elements away
- substitute one or more elements
- remove a connection
- change a connection
- connect an element to another element
- change a process sequence (usually for process patents)
- eliminate a process step (usually for process patents)
- change an attribute

The proposed ideas were altered and refined using some of these strategies discussed above. The refined ideas were then converted into a design in which preliminary actions were performed on the coating agent as well as the semi-finished paperboard by electrostatically charging them with opposing polarity to enable a strong adhesion between them. The coating agent was then ultrasonically pulsed to create a fine mist to control the amount of substance to be deposited on the paperboard. The mixture was then to be deposited on to the paperboard using a system of nozzle assembly with air assist. An embodiment of this design is shown in the Figure 4. A detailed layout scheme for application is also shown in the Figure 5.

4. Summary and Conclusions

The current methods used in paper industry for applying a coating agent to paperboard to produce the desired optical characteristics of the surface and improve the overall mechanical properties of the paperboard were found to be inefficient. While industry experts agreed on the need to reduce the waste created by the process and other inadequacies of the existing coating system, they were unable to generate the next generation solution primarily owing to the psychological inertia. Expertise, emotions, prior experience, and the cognitive style of the experts contributed to the psychological inertia.

TRIZ techniques such as function analysis, ideal final result and contradiction modeling enabled the reformulation of the problem in new ways. Subsequently inventive principles and function oriented search was used to generate the next generation solution that borrowed principles from other industries. An application for a utility patent for the new design is pending.

References


Introspection—Insight—Innovation Problem Solving for Innovation

Ed. N. Sickafus

Ntelleck, L.L.C. 27981 Elba, Grosse Ile, MI 48138, USA

Corresponding author. Tel.: +1-734-675-8501 E-mail address: ntelleck@u-sit.net

Abstract

Present day heuristic driven problem-solving methodologies (i.e., structured problem-solving methodologies, SPSMs) use logic throughout the process of solving a problem. This genre of problem solving methodologies is now brought into question in light of new research results of cognitive scientists in this century. [1] Their research show that the human brain does not use logic in solving a problem – an idea suspect, but not proven, for over a 100 years. At issue is the overrated and now contentious use of logic in SPSMs; namely, problem-statement, and heuristic driven logic. Question: What about their successes? Answer: Correlation does not prove causation. To address this issue, a new logic-free problem-solving methodology has been developed called introspection—insight—innovation (I3). Heuristics have been developed that aid the problem solver in skirting use of logic throughout the problem-solving process.

Both SPSMs and I3 are capable of finding the same solution concepts from the same brain. However, I3 eliminates the unobvious constraints of logic, thus widening its search in solution space. This avoids logical problem statements, logical analyses, and their consequential limitations of solution searches. Conventional SPSMs are reviewed to draw attention to their burden of logic. For comparison purposes, USIT (unified structured inventive thinking) is used as a surrogate example of SPSMs. Then I3 is defined and illustrated. Its heuristics are defined and examples are provided.

Key words: Type your keywords here, separated by semicolons ;

1. Strategies of conventional SPSMs

Cognitive science research in the 1950s produced the lateralization model of the brain with the left-hemisphere and right-hemisphere using different protocols in thinking. Left preferred logic and language while the right preferred intuition and metaphor. The model was adapted into problem solving and exists today in some SPSMs, though the psychology community deprecated this model early in its life. A new model of brain physiology in thinking has come available from cognitive science laboratories in this century called the bi-level model. It is the basis of this writing.

This paper addresses the excessive use of pseudo logic in problem-solving methodologies. All PSMs use heuristics. All lack justification based on cognitive science research results that connect brain physiology in thinking to logic of the heuristics in use. Justification of these heuristics was based solely on their satisfactory results since such fundamental cognition research had not been done until this century. Since results of the heuristics extant were not challenged, and still are not (and need not be), and no cognitive science results refuted them, it was a mute issue. Lack of any challenges to their pseudo logic may be related also to the intentionally clever use of language in well-defined problem statements and their intentionally close ties with the language of heuristics. This is particularly evident in the USIT methodology, as will be seen.

Now we have new results from the laboratories of cognitive scientists that find rather amazing insights into how the brain works in problem solving. For starters, it uses no logic! [1] They propose a two-level model of the brain consisting of the conscious and the subconscious. The subconscious finds solution concepts and proffers them to the conscious. These concepts, if accessed by the conscious, are then voiced logically by the conscious. This discovery poses a concern for all SPSMs using logic. Does the logic put forth in the problem statement, problem analysis, application of solution concepts, and all heuristics impose hidden constraints on the subconscious? If so, the subconscious is surely missing
opportunities for investigating solution space. And, if so, it poses a huge waste of energy and resources in the up-front preparatory effort required of structured problem-solving methodologies.

In order to justify the opportunity to introduce a new logic-free problem-solving methodology, I first will summarize the USIT methodology in terms of problem-statement based, logical heuristics. Conventional SPSMs begin with a problem statement. The following example is based on the logical heuristics of USIT (designated as *V for verbal and *G for graphic). [2] Its strategy is divided into three stages: problem definition, analysis, and solution procedures, of which the first is summarized in a partial flowchart (Fig. 1).

1.1. Stage I SPSM – Problem Definition to Problem Situation Information

Often problems are presented in vague terms and even more often lead to unexpected complexity as additional problems are discovered while developing a well-defined problem statement. *V: Information is gathered to deepen understanding of the problem and widen its scope to cover accompanying issues.

Information is analyzed first to identify multiple problems. *V: A minimization heuristic is used to eliminate one object at a time until all objects that do not contain the problem are removed. The remaining problems are ranked and one selected to solve first. *V: You can’t solve multiple problems at the same time. *V: A problem statement is written, which qualifies as a well-defined problem. A well-defined problem must be structured appropriately for the problem-solving methodology to be applied. *V: Select a point of contact between objects of the problem where an unwanted effect exists (the problem). *V: Describe the unwanted effect, F (a broken function) in terms of contacting objects (Os), each having an active attribute, A, that maintains or alters the function, F.

\[ O_1 - A_1 \]
\[ F - A_1 - O_3 \]
\[ O_2 - A_2 \]

Fig. 2. A graphic heuristic of two objects: \( O_1 \) and \( O_2 \) are in contact with object \( O_3 \); each has an attribute \( A \); and the problem has a malfunction, \( F \).

*V: Generification of verbal and graphic problem statements elevates the problem to the conceptual level where metaphors broaden one’s thinking.

The graphic heuristic, Fig. 2, is taken from the advanced version of USIT, which already eliminates a number of heuristics. [3] Heuristics shown here emphasize how logically tied together are all the features of a problem statement to its subsequent analysis and solution – a consciously planned effort. Six verbal and 2 graphic heuristics were used to this point.

1.2. Stage II SPSM – Problem Analyses


The closed-world method (CW). A problem solver is limited to the use of the original set of objects defining the problem and analyzed with graphic heuristics. (*VG)

The CW algorithm. The functional relationships of objects in contact are focused on. (*VG)

OAF Statement. Object-Attribute-Function statements are generated in order to identify and characterize the effective, ‘active’ attributes of the CW-objects. (*V)

OAF-Diagram. An OAF diagram is constructed to serve as a heuristic device in the application of solution techniques. (*VG)

Single-Object Function Diagram. Functions of single objects are investigated. (*VG)

QC-Graph. The object of this analysis is to make a qualitative change in a problem characteristic in order to create an inventive solution. (*VG)

The Particles Method (PM). In the PM the problem solver chooses an ideal solution to a problem then, in a series of morph cartoons, works back to solutions. The underlying strategy of the PM is to assume success then determine what you would have the particles do to get there – morph by morph. (*VG)

And/or Tree. The particles actions and properties needed from the ideal solution become points of focus in the solution process. (*VG)

1.3. Stage III SPSM – Solution Techniques

Solution techniques are now applied in order to find multiple conceptual solutions to a problem. The techniques include five broad, logical heuristics: Uniqueness, Dimensionality, Distribution, Pluralization, Transduction and Generification. Solution techniques often involve the problem-solver’s sketches of choice, which are heuristics. Each solution technique focuses on one or two problem characteristics at a time.

Logic of the left-brain hemisphere was the model of the brain used in early USIT. [2] In the lateralization model, logic was considered to overpower intuition of the right-brain hemisphere. To address this generification was introduced as a solution technique to mitigate logic. Soon after the bilevel model of the brain was published, I began to modify USIT and introduced Hazy Heuristics. Hazy heuristics was published as a prequel to this paper in 2014. [5]

In the above USIT example there are 16 logical verbal and 8 logical graphic heuristics. In practice one usually thinks of
others, which may or may not be verbalized but most often are sketched. This trend implies that heuristics are gradually learned and don’t require references. And it accounts for the practitioner’s gradual move away from the tedium of structured analysis by adopting shortcuts.

2. Strategy of Introspection–Insight–Innovation (I3)

The strategy of I3 is based on these laboratory discoveries of cognitive scientists [1]:
1. Introspection is a viable research tool.
2. The subconscious discovers solution concepts before the conscious.
3. The role of the conscious is to voice these discoveries for internal and external communication.
4. The subconscious finds and proffers concepts to the conscious and awaits conscious access of the idea, which it may or may not access.
5. The subconscious is considerably faster than the conscious and finds multiple offerings of which some may be accessed and others overlooked.
6. The lag of the conscious behind the subconscious (~1/3 sec.) creates an unstable threshold between attention to an idea being proffered and its conscious access.
7. While the mind is vigilant it may become aware of faint ideas that seem to come and go from attention.
8. The mind must make conscious access of an idea to gain insight and be able to voice it.

I developed I3 by adopting these cognitive science discoveries with two other features, eliminating problem-statement logic and adding methods for acquiring attention with conscious access – for a total of ten logic-free heuristics.

Elimination of problem statement logic is not necessarily an easy pill to swallow. It necessitates an end to conscious, logical processing of a problem situation once the original vague problem has been expanded to a problem situation. That means no analyses or application of solution techniques are required. Since the subconscious leads the conscious, the subconscious knows what the problems are and proceeds to find solution concepts. Without logical constraints these ideas appear sort of randomly. At least it seems that way partly because of conscious’ slow access and partly the random nature of the attention-access threshold.

In addition to eliminating problem-statement logic, a method of visiting the attention-access threshold, is needed. Most of us have had this experience accidentally at one time or another. It can happen, for example, when daydreaming, falling asleep, or coming awake. Now we need to be able to make it happen when needed.

Look at Fig. 3 and imagine describing what you see to someone. I see 12 gray circles, equally spaced on an undelineated larger circle with an X at the center. I have consciously accessed the image and I can describe it. Do you agree with me? Now consciously access the X and continue staring at it for a few seconds. As you stare at it you will note the circles becoming faint, disappearing, and reappearing, all in some random fashion. The randomness will differ between observers. This is strange. We went from conscious access of an image we all agreed on to an unstable one we can’t describe. I liken this to daydreaming on the attention–access threshold.

In Fig. 3 is shown a simulation of the unstable attention-access threshold [6]. The heuristic for attaining this state is to consciously think through the problem situation (not statement) in whatever manner comes to mind while slowly relaxing the mind as if taking a nap. I’ve done it often enough that I even get brief glimpses of ideas while sitting at a table with family and friends, but not paying close attention to the conversation. This works easily for me because I have a serious hearing loss.

I3, like USIT, begins with a typically vague problem that requires collection of information for better understanding and broader scope. More information is better, but no problem statement is required. The gathering of information supplements short-term and long-term memories and it establishes in memory the problem situation to be analyzed and solved without logical heuristics.

3. Example of problem solving using I3

From the beginning I had not yet decided on a problem to demonstrate. I wanted one that is new to me, so that I can develop and record new ideas as they arise without preconceived ideas - a fresh challenge to my subconscious. I expected to find a problem and immediately one or more ideas as they passed through my mind. In effect, I am attempting to see what my subconscious can do if left free. Since I have not been given a specific problem to solve, I’ll let one develop in my subconscious. To do that, I’ll simply begin thinking of problems I have given thought to in the past and see if the subconscious presents any new ones. This is a ‘logical’ step since by now my subconscious is aware of my need (S precedes C). Of course, since I could not collect situation information in advance, my conscious will automatically rely on the current state of my stored knowledge.

To pre-empt logic, I will not voice the problem to be solved first; that will become evident when solution concepts arise. Of course, my subconscious has participated in this writing all along – including this sentence – and knows what my problem
is, which is to find a new problem. Hopefully, it won’t let me down.

Recent problems I have thought about, which are coming to mind now, include, breaking pencil leads, non-spilling coffee cups, personally controlled hearing aid filters with noise cancellation, malfunctioning 3-way light bulbs, non-snagging fish hooks, small desk-top book binders for binding short articles. * There’s one I haven’t thought of – automatic book binding! Here goes.

In the following description, notice the objects (underlined) and their attributes (in cursive) use relatively generic words as compared with specific engineering terminology. No graphics were used thus rendering it the more generic.

As it came to mind, I had an immediate thought of a desktop printer that could fold each sheet of paper as it came out of the printer. I also saw how it might have come to mind. I have cruelly bound a couple of booklets in the past using the booklet-printing mode of my printer (long-term memory). Two are lying within sight here on my desk, but without conscious awareness until this moment. The next stage would be to apply glue to the folded crease on each page and stack them, lined up with edges even on two sides of one corner, and weighted or pressed together while the glue dries. Gluing could be done by passing a page over or under a narrow spray or brush as the paper left the printer in their pre-formed folded shape. They then could land atop of each other and, finally, be clamped in place to let the glue dry. Trimming the edges could be done individually as each sheet left the printer to avoid need later of heavy paper cutter device. The edges of each successive sheet could be trimmed in a progressively wider strip so that the stacked, folded-pages would be aligned in the process. QED (I’ll bet you thought of other ideas as I described mine. Problem-solving minds keep busy while ideas spark ideas.)

That was, for me, an interesting exercise. I have made small crudely bound books but have never thought of automating the process. As I was writing I could visualize the mechanical parts needed and imagined creating the machine drawings for someone to build one. I find my crudely made booklets very useful for proof reading various documents on the run, but they take too much time to make.

Notice that no structured heuristics were used. In fact, I was not aware of using any heuristics. Logic, if used, was used in voicing the written descriptive paragraph. And I had not thought of a booklet printer before this exercise. It came to mind as I was typing ideas. Planning started as automatic folding came to mind. Several potential problems were solved during the process of typing. These include folding, stacking, aligning, gluing, pressing, and trimming. All were first ideas that came to mind; i.e., no advanced development or engineering was done, and no specifications or equations were used. These are purely pre-engineering concepts that can now be turned over to an engineer for proof-of-concept demonstration.

This imaginary product could be engineered in multiple ways and possibly merit multiple patents along the way, as happens in problem solving.

The example used a technique of USIT to get started solving a problem. Namely, I selected a starting point in solution space; i.e., the first step in a thought path. [3] In this atypical case, I needed to find an undeveloped idea that I had not investigated in the past. I found it by simply starting to name problems I have previously thought of. A major assumption in this case is that the subconscious already knows what my problem is at this point and can bring new ideas to mind.

Another distinction of I3 compared with conventional SPSMs is the transition from a logic-driven problem statement to a no-logic situation description (See Fig. 1). When object numbers are minimized to discover multiple problems, and eliminate all but one, this draws attention to distinguishing details of the remaining objects. Attention is further sharpened as emphasis is placed on object’s active attributes. The result is a well-defined problem statement. On the other hand, when information is collected en masse for I3, in order to deepen and broaden understanding, no problem statement is formed. Consequently, subconscious focus on logic constraints is weakened. We have instead of a single-problem statement, a broad overview of the problem situation. That focus has been weakened is evident in the conscious-subconscious threshold when ideas fade in and out of attention.

4. Falsification

For a theory to be viable it must be falsifiable. This appears to present a problem for proving the theory of I3. Its heavy dependence on introspection and on daydreaming-like thinking, are potential barriers to falsification. Until the cognitive scientists progress further with the bilevel model of the brain, it may be necessary to depend on personal experiences of problem solvers.

Here, for example, is a positive note: Dr. Shahid S. Arshad, Applied Innovations, Sydney, Australia, informed me that he used hazy heuristics successfully to solve a TI programming problem. His paper was published in the TRIZ Home Page in Japan.

5. Conclusions

A new problem-solving methodology, I3, has been explained in theory and demonstrated in practice. It is the first methodology to be based on cognitive science research results regarding how the brain thinks and how it uses no logic. Functionally it depends on refreshing and supplementing short-term and long-term memories with verbose information about the problem situation. Subconsciously the brain then operates from memory to produce solution concepts. It does this without constraints of logic in problem statements, analysis, and solution heuristics. Ten logic-free heuristics were defined.

References


Abstract

A business system consists of a number of components and interactions between them. It also involves various interactions with its supersystem. Key system and supersystem components and interactions can be presented by a business model which provides a unified framework to model a large diversity of business systems, value creation chains and networks.

It is obvious that during evolution, a business system tends to face different types of obstacles and barriers related to various parts of business processes and activities it runs itself or in which it participates. Similar to technology and engineering, there are a number of universal high-order patterns of solution strategies which resolve contradictions and overcome barriers created by solutions known within the system’s domain.

In some previous works it was argued that such patterns are identical to the patterns recognized for technical systems and presented in the knowledge bank of TRIZ. Although it appears to be partly true, our studies show that there are also a number of unique patterns specific to business domain.

The paper presents work in progress related to structuring such patterns, describes possible scenarios of business model innovation and provides several illustrations of specific and generic patterns of business model innovation strategies.

Keywords: TRIZ; Business Model Innovation, Systematic Business Innovation

1. Reinventing Business Models

1.1. Importance of Business Model Innovation

The concept of a business model innovation has been actively discussed lately. According to [1], "... a Business Model is a description of how your company intends to create value in the marketplace. It includes unique combination of products, services, image, and distribution that your company carries forward. It also includes the underlying organization of people, and the operational infrastructure that they use to accomplish their work".

The necessity of paying close attention towards a business model an organization deploys on its own or participates in, emerged due to highly increased competition. In the past, almost all business organizations used traditional ways of performing business operations for either providing services or production and delivery of tangible products to the customers. Physical, logistic and geographical limitations helped business organizations to successfully sustain performance and grow without inventing new ways of doing business.

The situation drastically changed in the mid 1990s. Development of the internet, introduction of highly efficient global transportation systems, emergence of software support of business processes with a capability of connecting and sharing data among remote locations lowered the entrance barrier to a global marketplace and provided medium-sized and small enterprises with a chance to compete on the global scale. Failure of a number of global companies with a long history such as Polaroid, Kodak, Olivetti and others which existed for dozens of years demonstrated that to survive and grow, to only innovate their value propositions which was
based either on tangible or intangible products (such as services) or on their combination was not enough.

It is important to distinguish between two large application areas when discussing business innovation:
1. Innovation of a value proposition based on the products and services created and developed by a business organization. Usually the result of such innovations are improved or new products and services.
2. Innovation of a value creation chain or a network, which are established to co-create and co-develop value propositions without affecting neither value propositions nor their components. While the results of such innovations directly impact business-related parameters and metrics, such as increasing sales, performance, market share, productivity, or decreasing costs, they deal only with a system which produces value proposition and not with the value proposition itself.

During recent years, many businesses gained a competitive advantage not through offering innovative products or services but through changing a way they perform business activities and organize their value chains and networks to make the businesses more effective and more efficient than their competitors. Therefore, the conclusion is that it is important to innovate business systems, methods and business processes to considerably improve value creation chains and networks.

1.2. Technical System and a Business System

There have been many discussions if TRIZ can be directly applied to innovating business systems and business models. One of the arguments against it due to the fact that the business systems operate with people and therefore they have different principles of evolution rather than technical systems. Unlike technical systems which are based on the laws of sciences like physics or chemistry, business systems depend a lot on psychology, especially on human decisions which can be irrational. As a result, when we use a model of a technical system we can predict its future behavior more or less correctly while when using a model of a business system we may not produce a correct prediction of its behavior.

In part, it is true. However today most of business systems operate on the basis of business processes which clearly define various aspects of a business system functioning and behavior. A modern business system possesses a well-defined structure and well-described relationships between its internal parts and their external system: a supersystem.

Studies already demonstrated that the fundamental TRIZ principles could be observed in a number of different non-technical areas. Research by B. Zlotin and A. Zusman on the evolution of organizations also revealed trends and patterns very similar to those which were found in technical TRIZ for evolution of technical systems [2], [3].

In addition to investigating parallels of evolution of technical and business systems, experiments were conducted with the use of adapted TRIZ tools to solve various innovative problems. For example, the use of such tools as Function Analysis, Root-Conflict Analysis, and Contradiction Matrix with 40 inventive principles appeared to be useful with modeling and solving specific innovative problems emerging within business systems [4], [5].

The first experiments with directly applying the TRIZ philosophy and some its tools to reinventing business models were discussed in [6]. This paper focuses on a strategy determining how a specific inventive business problem can be solved by producing a change of a business model.

1.3. Modeling a Business System

According to TRIZ, a technical system uses energy received outside to perform a number of operations and functions either to create, or maintain, or produce a required change of a product which does not belong to the technical system. For example, a coffee machine uses electrical energy to heat water and pass it through the chamber with grinded coffee powder to transform clean water to the coffee drink. Any technical system operates within the context of a specific purpose.

A business system (company, organization) is created to produce a certain tangible or intangible product, which after being delivered to a customer, will provide an owner of a business system with revenue to compensate all types of investments and costs to generate profit provided by the added value. A business system deploys a number of business processes and activities which add value after each activity in each business process.

Instead of energy, a business system utilizes financial means to enable organization and support of processes within a value adding chain to transform an input from a supersystem (supply) to a product to be delivered to the supersystem (customer). Based on these assumptions, we can define a model or a business system provided by a business organization similar to a model of a technical system which includes at least seven components (Fig. 1).

![Fig. 1. A complete business system by analogy with a complete technical system.](image-url)
value creation process it is important to include it to the business system model to obtain a comprehensive picture of the system.

Nevertheless, it is important to see the difference between a model of a business organization, where all the assets involved belong to the organization only and a model of business, which includes either the entire organization, or its part, or a combination of a system with the components of its supersystem involved to the value creation network (for example, customers can become co-developers). The same organization or some its part can therefore be engaged to a variety of diverse business models whereas the same business model can involve separate business organizations and customers (Fig. 2).

1.4. Business Model Canvas

The model of business system presented in Fig. 1 illustrates the law of business system completeness and highlights the necessary components of a business organization to make it viable and sustainable.

This model is rather generic and its intention is to present the necessary components of a complete business system. An actual system can contain a number of additional elements involved to the value creation chain or network at both system and supersystem levels as well as components which are not directly involved to the value creation chain in terms of an end product (e.g. audition). In order to put the complete model of a business system to practice, one can use different frameworks, for example the Business Model Canvas approach [7]. The Business Model Canvas propose to generate specific instances of business models by completing the following blocks (Fig. 3):

- **Customer Segments**: An organization serves one or several Customer Segments.
- **Value Propositions**: It seeks to solve customer problems and satisfy customer needs with value propositions.
- **Channels**: Value propositions are communicated and delivered to customers through communication, distribution, and sales channels.
- **Customer Relationships**: Customer relationships are established and maintained with each Customer Segment.
- **Revenue Streams**: Revenue streams result from value propositions successfully offered to customers.
- **Key Resources**: Key resources are the assets required to offer and deliver the previously described elements.
- **Key Activities**: all types of activities needed to perform and support the above mentioned building blocks.
- **Key Partnerships**: Some activities are outsourced and some resources are acquired outside the enterprise.
- **Cost Structure**: The business model elements result in the cost structure.

The Business Model Canvas framework has became widely popular due to its clarity and simplicity. It is an advantage since there is no need to explain it to business people who are familiar with it. One can use the Business Model Canvas to investigate and obtain information about inefficiencies and bottlenecks of any business. Later this information can be used to propose the ideas how to reinvent the existing business model or create radically new business models.

2. Business Model Innovation Strategies

2.1. “Observe and copy”

Most prominent business model innovations have been occurring as a result of using the “observe and copy” paradigm. In addition to creating a very new, so-called “pioneering” business models, the most radical business model innovations result from transferring a successful business model or its part (or a block in Business Model Canvas) from a remote market area preferably dealing with a very different type of a product to the existing market area. For example, a company producing and distributing a certain product for food market might “steal” a working idea from a postal service to innovate a specific block of its business model. Such approach is also known as “cross-industry innovation” [8].

One of the early examples of such pioneering business model innovations is based on the invention of the franchising model of marketing and sales by Singer Sewing Machine Company in 1851 [9]. Albert Singer, the founder of the company is widely considered as an inventor of a franchising model, although there is some evidence of earlier cases of franchising introduced by German ale brewers, which granted marketing rights to independent taverns. A hypothesis states that Albert Singer could possibly observe these taverns and “copied” the idea to try to increase the sales of his machines,
although this fact is not mentioned in the literature available. Later the franchising model was copied by other businesses operating at different markets. Nevertheless, many businesses today could probably benefit from becoming franchisors as well, but they do not use this model for a number of reasons. Among these reasons, the most important one is that the franchising model has never been used at their markets and the companies have no confidence that it will be successful for their enterprises.

One can say that the business principle of franchising helps delivering the function of products distribution differently than the business principle of direct sales or sales through distributors. While the function remains the same (to sell a product), the principles of delivering the function are different. However it does not mean that the direct sales have to be always replaced by the franchising model to increase the performance and scale of products distribution. There might be certain constraints under which the franchising model might lead to decreasing the sales performance or increase cost of sales, especially within B2B market.

Regarding technology innovation, a principle “observe and copy” can be used for technology transfer or technology diversification, thus implementing “technology push” paradigm to create new technological innovations based on the same physical or technical principle but which have different purposes for different markets.

The approach based on using the combination “principle - function – market” can be compared with the TRIZ Database of Technical Effects [10], or with a more recent tool known as Function-Oriented Search [11], where a specific technology for delivery of a generic function is searched in a technology domain outside the technology domain of an innovator. However technical functions tend to be more specific than business ones. It greatly increases the total number of specific technical functions compared to the number of business functions. In addition, every business organization within the existing economic paradigm targets at growth, which is the main goal of business development and is often considered as a business function itself.

2.2. Scenarios of Business Model Innovation

There can be four scenarios of business model innovation (Fig. 4):

1. Creating a radically new business model principle that has never been used before at any market. An example is given above, invention of the franchising model by German ale breweries.
2. Copying an existing business model principle from a radically different market, or a domain. The example is implementing a franchising model by A. Singer to distribute his sewing machines.
3. Copying an existing business model principle from a “neighbourhood” domain. Neighbourhood domains can be defined as domains producing similar functional types of products distributed within the same market, both tangible and intangible. For example, the machines for processing food can be considered neighbouring even if the machines have different purposes and functionalities. The same is relevant for two businesses which sell different types of insurances.
4. Copying an existing business model principle from businesses residing within the same market. The example are fast food restaurants, like McDonalds or Taco Bell which followed the franchising model of Howard Jonson’s restaurants launched in the 1930th in the USA. Another example of the same market business innovation was introduction of the assembly-line by McDonalds fast food chain which was very quickly copied and adapted by its competitors [12].

Fig. 4: Types of Business Model Innovation

It is not often a case when a whole business model is copied. In most cases, only a specific business principle is copied which determines a platform on which a particular business model block operates.

All cases of business innovation can be divided to two large groups according to the two types of causes which trigger these innovations:

a) A new innovative solution results from solving a specific problem which emerged either within an existing value creation network or between a business system and its market. For example, a company starts losing its market share and to prevent its further loss switches to a different business model. In such case it is clear what a source of the problem is and a new solution results from solving a specific problem.

b) A new innovative solution results from successful implementation of a novel business model or adapting a novel business principle regardless any existing problems. For example, a company switches to a novel business model after becoming confident that a new or an upgraded business model will ensure its faster growth even if a company feels stable at the moment.

3. Typical Patterns of Business Model Innovation

3.1. Specific and Generic Solution Patterns.

The next question to answer is what these business principles are and if there is any framework to place them to a systematic use.

As follows from the TRIZ philosophy, open problems which are not limited by a predefined number of possible solutions, can be attacked by first creating a model of a problem by abstracting certain features of the problem (e.g. by defining a contradiction), and then by applying a typical
solution pattern drawn from the TRIZ knowledge bank. Different categories of such patterns exist in modern TRIZ for technology and engineering: inventive principles, inventive standards, scientific and technical effects structured according to technical functions. Separation between these categories is defined by the level of knowledge abstraction and a type of a problem model.

Similar to the inventive principles presented in TRIZ for technology and engineering, innovative business principles can help with eliminating barriers created by the limitations of the existing business models. For example, a principle of franchising mentioned above can be used to increase products distribution at the mass consumer market. It can be seen as a very rough analogy to a physical effect, for example, of heat expansion which can be used to deliver a function of changing object sizes. However the principle of franchising is a specific solution, and it can be considered as an instance of a more generic innovation (or problem-solving) strategy.

The second category of knowledge is formed by generic strategies of reasoning towards new specific solutions which might become new specific solution patterns. Rather than suggesting a specific solution principle, these patterns recommend a very general solution strategy that can be used to find a new or identify an existing solution principle. For example, the TRIZ principles of physical contradiction elimination define high-level strategies of thinking rather than offer specific solution principles like physical effects.

To illustrate the difference between these two categories of principles, let us look at the example of innovating a business model of producing and distributing butter. At a company, the following situation emerged: during summer period, when cows consume fresh grass from green fields, the chemical composition of milk is different from winter periods when cows are fed with hay. As a result, butter produced during winter is different from butter produced during summer. One of the differentiating features is that so-called “summer butter” is soft and creamy while “winter butter” is hard. But both types of butter have their own market niches: soft butter is good for everyday home consumption while hard butter is requested by bakeries. Since the company operates with “just in time” delivery policy, the winter butter has to be prepared and stored during the entire summer in cold warehouses, and as obvious, it imposes high costs.

A seemingly easy solution direction would be to modify the milk composition. But it is not allowed to add any components to transform winter butter to summer butter due to highly restricting industry norms and regulations. This challenge can be approached in two ways:

a) Since a solution to the problem is not known within the dairy products domain, the company has to search for possible specific solution pattern (business solutions) which might be available in some other domain that experiences the same or a very similar problem. Once a promising candidate solution is discovered, it can be examined and tested if it can be adapted by the company.

b) Instead of searching for existing solutions in the neighborhood or remote domains (or if such attempts fail), a problem can be further analyzed, modeled and a certain generic solution pattern can be applied to invent a new solution. Such generic solution patterns are similar to the TRIZ principles used in technology but are defined based on studying how innovative problems are solved with respect to innovating business models.

In case of using the first scenario it is possible to use a known solution widely used by fruit delivery companies located in northern countries, which purchase fruit locally in Northern hemisphere in the summer period and import it from other countries which are located in the Southern hemisphere during winter period. Such a solution can be aggregated to the following specific solution pattern: “Splitting supply or delivery between most optimally located points in time and space”.

In general, such specific solution pattern is most often used to innovate such blocks of the business model as key partnerships and cost structure.

In case of using the second scenario, a new solution can be generated without referring to already known and existing solutions but through formulating a problem, defining a problem model through abstraction, and applying generic solution principles as thinking recommendations to come up with a new solution.

For example, the following contradiction can be formulated: “hard butter must be soft in winter time”, and then the generic patterns can be used: for example, resolving the contradiction with the principle of “separation of conflicting demands between parts and a whole”. The solution can be that butter might consist of hard clusters located within a creamy summer butter. In this case, the volume of summer butter stored during wintertime can be considerably reduced.

3.2. Examples of Specific Solution Patterns

The specific solution patterns for business model innovation aggregate solutions which are most frequently used for innovating different blocks of business models and which can be universally applied. In contrast to generic solution patterns, they can directly lead to proposing specific solutions according to a pattern given.

Each specific solution pattern is supposed to be applied to a certain part of a business model block. In our studies, we use the Business Model Canvas approach mentioned above to identify such patterns.

Several such principles are shown in Table 1.

Table 1. Specific Principles for Business Model Innovation

| Principle: | Leverage differences between components of a business system or components of a value proposition as much as possible. |
| Comment: | Identify if increasing the difference between the components of the same business model block will create advantage. |
| Business blocks: | Key activities; Value Proposition; Key Resources. |
| Examples: | • A “Razor and blade” business model: |
The basic idea of introducing the generic solution principles is that once a problem solver faces a situation when none of the specific solution patterns can not be applied to obtain a solution required, a deeper understanding of a situation and a more creative approach to generation of a solution is needed.

Although there is the collection of 40 Inventive Principles adapted to business and management [4], a number of practical projects on business innovation demonstrated its limited applicability since the principles were extracted from analysis of technical information and therefore studies of business innovations had to be done. The collection of generic patterns is applied to the contradictions emerging within business models identified by the analytical TRIZ tools, such as Function Analysis, Root Conflict Analysis, or Value Conflict Mapping [5]. Their application is not limited by improving business models only, they can be applied to resolving contradictions emerging in business processes, activities, as well management conflicts.

Table 2 shows several examples of such principles.

Table 2. Generic Principles for Business Model Innovation

<table>
<thead>
<tr>
<th>Principle</th>
<th>Separate conflicting properties between parts and a whole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comment:</td>
<td>Each “part” delivers a certain function or possesses a certain feature while many parts form “a whole” which provides an inverse value of a function or possesses inverse feature.</td>
</tr>
<tr>
<td>Examples:</td>
<td>• A small company can run big projects by forming temporary teams consisting of a number of small companies with different skills.</td>
</tr>
<tr>
<td></td>
<td>• A venture fund allows small investors to invest to big projects.</td>
</tr>
<tr>
<td></td>
<td>• Several small companies purchase and share an expensive booth together at an exhibition.</td>
</tr>
<tr>
<td>Principle:</td>
<td>Transfer one of the conflicting demands or a function to supersystem</td>
</tr>
<tr>
<td>Comment:</td>
<td>Supersystem consists of everything which surrounds and interacts (or can interact) with a business system but does not belong to the business system.</td>
</tr>
<tr>
<td>Examples:</td>
<td>• Sales performed by independent distributors.</td>
</tr>
<tr>
<td></td>
<td>• Outsourcing an important activity which requires top skills to an established and reputable supplier.</td>
</tr>
<tr>
<td></td>
<td>• Hiring professional marketing agency to perform market study for launching a new product.</td>
</tr>
<tr>
<td></td>
<td>• Attracting university professors as consultants.</td>
</tr>
<tr>
<td></td>
<td>• Hiring interim managers to handle critical issues.</td>
</tr>
</tbody>
</table>

Currently, the work on developing the collection of both generic and specific solution patterns is in progress. It is based
on the analysis of over 1000 different cases taken from diverse industries.

4. Conclusions

Until now, the applications of TRIZ to business and management were limited to translating and adapting the knowledge base of technical TRIZ to business and management domains. However over a dozen of years of practical applications of TRIZ for business and management tasks have shown that despite the distinct similarities between technical and business systems, there are certain differences specifically relevant for business models and these differences have to be studied to develop a knowledge base specifically focused on business innovation.

Currently this work is in progress, and the preliminary collections of both specific and generic principles for business model innovation are being tested in various projects.

References


Competency-based learning in TRIZ – Teaching TRIZ-forecasting as example

Christian M. Thurnesa*, Frank Zeihselb, Rudy Fuchsc

a OPINNOMETH Center of Competence, University of Applied Sciences of Kaiserslautern, 66482 Zweibruecken, Germany
b Synnovating GmbH, Mozartstr. 25, 67655 Kaiserslautern, Germany
c University of Applied Sciences of Kaiserslautern, 66482 Zweibruecken, Germany

* Corresponding author. Tel.: +49 631 3724 5265; E-mail address: christian.thurnes@hs-kl.de

Abstract

For the future dissemination of TRIZ a widespread learning and understanding of its elements is essential. For societal learning and change towards “thinking TRIZ”, a broad dissemination of TRIZ-basics as well as advanced methods are necessary. This article describes empirical research on usage of contemporary competency-based learning tools and settings for building up profound knowledge and skills with a very complex TRIZ-method (here: DE-Directed Evolution ™), as done in 2014 and 2015. The article shows two main aspects: First, the usage of competency based learning techniques is explained, as used in an experimental environment of a class at the author’s university. Learning techniques like the learning diary and the learning journal are very different from traditional learning methods. They focus on the individual and his or her own development instead of just transmitting knowledge and rehearse the usage of tools. In this way the result of this approach is not only knowledge, it is a changed mind and maybe a changed behavior – and this may be part of the base for a societal learning and change towards a better world for this individual as well for the society on the whole. Second, the object of this learning is in this example the DE-method – a TRIZ-forecasting derivative originated mainly by Boris Zlotin and Alla Zusman – that concentrates more on changing to a desirable future than just knowing the future, so it broadens the individuals horizon. The article describes experiences and opens discussion for a future oriented learning of TRIZ.

Keywords: TRIZ; teaching; learning; competency; Directed Evolution

1. Introduction

Teaching and learning of TRIZ knowledge and methodology is of fundamental essence for disseminating TRIZ - in the past and even more in the future. Hence basic training courses are offered to learn the tools of classical TRIZ. But what about more complex TRIZ methods as for example Anticipatory Failure Determination or TRIZ-forecasting? Is it possible to learn these with the same setting? Or is it necessary to change the way of learning and the learning experience for the students?

In this article the authors show how contemporary competency-based learning tools and settings for building up profound knowledge have been used in the teaching of TRIZ-forecasting to master’s degree students at the University of Applied Sciences of Kaiserslautern.

Chapter 2 gives an overview about the learning content and the learning tools. Chapter 3 is written from the perspective of a student as an experiential report. Finally chapter 4 concludes the main aspects of this paper.

2. Learning TRIZ with competency-based learning tools

To give a glance what the students are supposed to learn a short overview of the Directed Evolution ™ (DE) is presented here.
2.1. The learning content: TRIZ-forecasting using the DE-method

According to an Accenture study in 2011, successful companies are able to jump from one S-curve to the next for best business performance [1]. To realize this, the company has to create more mature products by improving them but at the same time it must be able to develop innovations for the markets. That means, that successful companies “ride” on one S-curve while preparing the next S-curve at the same time and gain an excellent overall performance (Fig. 1) this way.

The Directed Evolution™ is a method that allows to find the next evolutionary step of a product or technology by following a well defined process [2]. It is based on the following assumptions [2]:

- The evolution of many objects, entities or constructs (e.g. technologies, products, social life) follows certain patterns of evolution.
- These patterns of evolution can be revealed by exploring the history of evolution of various systems.
- Identified patterns of evolution can be utilized to predict and direct the evolution of the system of interest.

The DE-method uses evolutionary patterns for technologies, markets, business, and social systems [3], [4]. The base for these findings has been the Theory of Inventive Problem Solving (TRIZ) (see [5]) that started the research of systematic structures in technology in the mid-1940s.

As a forecasting method, DE differs fundamentally from not TRIZ-based forecasting methods (see e.g. [6], [7], [8]) that utilize techniques like trend extrapolation, morphological modelling, the Delphi Method and other methods that are mostly based on probabilistic modelling of future characteristics of systems [2].

The DE-method can be explained, as a procedure following the path shown in Fig. 2.

Conducting a DE-process, first the system has to be analyzed in its actual condition with its actual system structure and system functioning. The results of this analysis help to understand the history of the system i.e. its states and conditions in the past.

The past of the system therefor is to analyze in the next step – gaining an understanding, why and how it could evolve to the actual state.

With the information gathered so far the process of synthesizing ideas for future systems may start (arrow 3 in Fig. 2). The application of identified patterns of evolution is essential in this stage. Ideas then are combined and adapted and turned into concepts. Furthermore some risk assessment has to be done.

If some possible future states of the system have been developed, they have to be interrelated with the actual system – this is made by detailing and breaking down the future concepts into evolution scenarios.

Finally the most promising evolution scenarios have to be chosen for realization and during the implementation, the process results continuously should be aligned with the results suggested by the appropriate evolutionary patterns.

The DE-process is very complex and not as linear, as fig. 2 implies. That’s why process descriptions (see [4]) and supporting software tools divide the whole process in a lot of steps and some of these steps comprise many sub-steps. The process structure used in the class contains nine steps [10]:

1. Analysis of the past and the main patterns of systems evolution
2. Setting goals for further systems evolution considering requirements and patterns of market evolution
3. Identification of relationships between systems evolution and the evolution of other systems
4. Analysis of constraints and resources and identification of possible evolution towards increased involvement of resources
5. Risk Identification (e.g. using Anticipatory Failure Determination [10]) and using cause-effect diagrams to explore further directions for evolution
6. Application of evolutionary patterns and lines to create solution ideas
7. Combination and further development of ideas to create solution concepts
8. Evaluation of the concepts, risk mitigation and treatment of unveiled problems
9. Planning the implementation
2.2. Competency-based learning

Basically, competency-based learning has the goal to enable the students to do the right things right, when appropriate and to learn how to change themselves if necessary to do this. Many traditional learning settings focus on the input of the learning, following the question ‘what should be taught’. The objective of competency-based learning is the outcome of the learning process and the related question is ‘what capabilities (or competencies) posses the student’ (see e.g. [11]).

So in this case, competency does not just mean to know about DE and to use the tools in the right way. In the concept of single loop, double loop and deuterol training (see [12]), the double loop learning and the deuterol learning are essential for the development of students competencies to use DE in real life in a useful way: Single loop learning is based on a target/actual comparison of actions (e.g. conduction of DE-steps). Double loop learning additionally comprises the reflection of the goals and action theories that are the base for the actions taken – it is the learning of doing the right things and the learning of changing and adapting own action concepts, behavior and value propositions. Deutero learning furthermore encompasses the reflection of the own learning process of the individual. Deutero learning in combination with single and double loop learning enables the students to understand themselves in the reality of their social system and to adapt their behavior in a way that probably leads to success and anticipates conflicts.

![Diagram of small process steps, learning diary and learning journal](image)

Based on [11], [12] fig. 3 shows the conceptual elements that have been used to support competency-based learning in the DE class:

- many structured actions in small portions, to create short cycle single loop learning on the tools and their usage,
- a weekly learning diary to reflect the insights from single loop learning and double loop learning – insights regarding tool usage and insights regarding why to use, under what conditions and with what mindset and value propositions,
- a learning journal at the end of the class to reflect how the individual lived through the learning process and how he or she deals with the own change.

2.3. Class setting

For teaching DE under the frame of competency based learning the students were asked to look for a product for that they want to develop the next product generation. Then they were asked to form teams to work together on a product but nobody was forced to work in a team. If somebody decided to work on a project by him-or herself, this was also fine.

So for 2014 there were 4 teams with 14 students working on a project and 2 students working on their own. Actually in 2015 there are three groups with three students in each group working on their topics.

Teacher and students meet every week for a three hour course lesson. The learning content is broken down along the phases and the nine steps of the DE process to fit to these 3 hour sessions.

So they get for example introduction into TRIZ basics like principles, they learn how to develop the models, they learn how to search for patents and so on. Every student got an temporary license for DE-software by Ideation International Inc. [10], that also shows the nine steps of the DE process and further more supports with information and examples regarding those single steps. The students can document their work in the DE software and do the requested modelling.

Because the biggest effort is laid out on the “doing” the students have to fulfill weekly assignments based on the lesson’s content of the week – this assignments are collected as one part of the learning diary. In addition every student is asked to write down a second learning diary entry every week and to submit it to the teacher in which the student is asked to reflect the work that was done in this week and the lessons learned. Guiding questions for this part of the learning diary are for example:

- What was done?
- What was difficult about that?
- What was good or surprising?
- What would be recommendations for improvement?
- Describe the quality of teamwork of this week.
- …

At the beginning of the next lesson these reflected impressions are discussed, obstacles are removed, and difficulties (as far as possible) eliminated. So here the aspects of single loop learning and double loop learning have priority. So step by step the students work on their product and week by week ideas grow for how the future state of the product could look like, always reminding that the future state to be realized is developed and selected late in the process.

At the end of the class, each student has to create the final learning journal. This is a portfolio that contains:

- the assignments of all weeks,
- the learning diary entries of all weeks,
• a final reflective report regarding the insights about the students own overall learning process and the changes identified in own behavior, value propositions, attitude etc.

The next chapter is written by student as experiential report to illustrate the topics described so far.

3. Experiential report – insights of a student

As a master’s degree student at the Kaiserslautern University of Applied Sciences, majoring in Logistics and Production Management, I had the valuable opportunity to experience TRIZ within an Innovation Management class, conducted by Prof. Dr.-Ing. Christian Thurnes with support of Dr. Frank Zeihsel and the Ideation International Inc. company. Through applying the DE-method, its systematic process steps and with the use of competency-based learning tools, innovative concepts of everyday objects were pursued. I concentrated on groundbreaking dental hygiene devices.

Within these steps students have to deal with a lot of modelling (e.g. models for Project Objectives, History of the Systems Evolution, Markets aso.), patent search, and deep web search. Addressing all that points seem to be overwhelming a student’s capacity for one semester. Therefor the approach of competency based learning was addressed in 2014 for teaching the DE to students. Currently in 2015 a new course with the same setting is conducted.

Referring to the systematic sequence of the DE-method, the process step execution and the respective lessons learned were documented in a weekly learning diary as well as a learning journal, finalized by a comprehensive reflection. Before having experienced TRIZ, I was rather convinced that creating innovations in a high quality and quantity is mainly a matter of ingenuity. Utilizing the DE-method, however, could possibly lead to a stringent documentation of the expertise-based ideas. The mentioned mindset should be challenged even without passing the first process steps.

3.1. Lessons learned within the various DE process steps

Already the project initiation with the use of various creativity techniques, such as “Change your point of view” and “Play with the scale”, helped me to broaden my way of thinking by minimizing my psychological inertia, which I only became aware of in retrospect. This early step was the prerequisite of creating a wide range of ideas in the sequel. In doing so, I became acquainted with a further helpful tool, the “Problem and Directions Formulation” diagram, a graphical method to determine potential starting points of the innovation development by analyzing cause-effect coherencies. In this early phase, an important lesson learned was to define the criteria for selecting solution concepts in a neutral manner, so that innovations are not pushed in one specific direction. Regarding my personal topic - the dental hygiene devices - I gained a first overview about the object, exempli gratia the categories of oral health devices, as well as the different types of tooth brushes, oral irrigators and tongue scrapers. First solution concepts were adumbrated as well as documented.

Process step two, the “Express Directed Evolution”, led me by creating an ideal vision of the dental hygiene device, for example a complete process automation and a maximal mobility without need of additional water. For me a further entirely new aspect was the approach to use main patterns of the devices evolution for creating future innovations, whereby s-curve models covering the ideality in course of the time were created. Crucial at this is to realize, if exempli gratia the technology of sonic toothbrush is well-engineered and if future technologies should be focused. In addition, the review of current macro trends, such as lifestyle changes and informational revolution, is one foundation of bringing an invention to an innovation.

A useful and entirely applied method of the DE process, especially within the third process step, the “Evolutionary Analysis of the system”, is the system operator (or 9-screen), a method to analyze the system in past and future sub- and super systems, which targets on the identification of interdependences. Furthermore, I experienced that considerations about how to eliminate the actual problem can stimulate the creativity. For example, dental plaque can be completely avoided with a revolutionary coating of the teeth. Analyzing predecessors, failed system prototypes and patent publications of the past were also greatly helpful on the way to create innovations.

Subsequently, within the process step four “Resources, constraints and limitations”, listing and analyzing the system resources, separated into substance, field and space resources, enabled me to capture additional ideas. In contrast to the beginning and in order to target the elaborating ideas, at this point the level of system change was determined. Besides a renewed reflection of the cause-effect diagrams in step five, which generated the highest idea quantity of all process steps, all ideas were first roughly elaborated, then, to finish the DE process, particularized.

The termed methods, tools and approaches of the DE process clarify my lasting learning effect. After completing all the various process steps, I am, contrary to my former mindset, highly convinced that especially the methodical approach leads to an unevenly higher output, even if the process steps are related to a high volume of work. Due to that, I will especially use the methods for comprehensive and complex interrogations of innovation in the future. One characteristic of the DE-method, that was also mentioned by all the fellow students, is the force to analyze the object in detail, which was almost always not apperceived. In the aggregate, I was able to create around a hundred diverse ideas during the course, an obvious argument for the success of the DE-method. As an example, one of these ideas, in my opinion a conception with a high level of ideality, is outlined in the following.

3.2. Mobile dental hygiene device for travelers

The desire of mobility, as a macro trend, is increasing steadily. One human need, which is highly affected by the mentioned progress, is the need for body hygiene. Especially if you are having, for example, a twelve hour flight, the desire can even increase. Up to this point, most of the time it was
quite difficult to brush your teeth while travelling. You had to find some type of stationary water supply, firstly, to have fresh water, and secondly, to drain the dirty water afterwards.

Therefore, following concept is an oral hygiene hybrid of a tooth brush and oral irrigator within one device, which is completely mobile and stationary water supply independent. Additionally, the device is equipped with an integrated, illuminated foldout mirror to monitor the cleaning success. The two basic components of the device are the handheld unit with an integrated battery as well as a charging station. The energy is transferred via electromagnetic induction.

The handheld unit, as the innovative part of the concept, is outlined in figure 4 in side view. As mentioned, it combines a sonic toothbrush and an oral irrigator in one housing. Both modules are powered with a common battery, which is charged by a secondary coil in the lower section of the housing. The sonic toothbrush module, consisting of an electromagnet and a permanent magnet, transfers the sonic waves to the brush head and is located in the upper section of the housing. Between battery and sound transducer the oral irrigator module is installed, which is connected with two plastic reservoirs at the outside of the handheld. Basically, the oral irrigator can conduct two functions: Firstly, the water pump is able to pump fresh water out of one reservoir. Secondly, dirty water can be absorbed into the second reservoir.

The water pump is able to switch the direction of pumping, whereby a nozzle is integrated at the top end of the brush head. With this nozzle the water can either be pumped out or be absorbed. The mentioned conception requires, for example, that the function “pumping” is connected with the fresh water reservoir only. Furthermore, the water pump is also able to absorb air, wherefore overpressure valves are incorporated in the reservoirs.

The lower brush head is permanently connected with the housing via the water supply pipe. Because of this, only the top component of the brush head can be substituted. For filling and respectively emptying the reservoirs, sealable apertures at the outside of the housing can be used. The foldout built-in mirror is located next to the battery, whereby an LED illuminates the oral cavity. Due to the vertical orientation, the mirror has no curvature and to operate the different functions the control panel can be used.

The process of cleaning can be as follows: To begin with, the operator applies tooth paste and activates the pumping function of the oral irrigator module for a short period of time, whereby fresh water is pumped into the oral cavity. After deactivating the oral irrigator module, the operator activates the sonic toothbrush module and cleans the teeth surface. When the cleaning is finished, the absorbing function is activated and the dirty water is absorbed. Subsequently, the operator irrigates the oral cavity by using the pumping and absorbing function again.

The cleaning of the interdental spaces is similar, whereby the pumping function is used to pump water out of the nozzle with high pressure. The pumping and absorbing functions have to be used alternately to avoid possible discharge. The mirror can finally be used to check the cleaning success.

3.3. Evaluation of competency-based learning techniques

As implied, the process steps of the DE-method were weekly introduced by the teachers and accomplished by the students until the next lecture. Utilizing this method, the complete DE process was documented in a weekly learning diary, based on the DE software. The conclusive learning journal was used to summarize the learning effects, as well as for a final reflection. In total, the DE process was passed through within ten weeks.

To start with the evaluation, it is important to outline that the DE-method does not only lead to innovation, but also the way the DE-method was taught in the class was itself innovative. Introducing the process steps weekly and having the students accomplish the steps in the aftermath on their own, keeps the students and kept me “doing” and really creating ideas step by step. Herewith, the way of teaching is contrary to most of the other university classes. Additionally, I feel certain that the incremental and active way of learning leads to a much higher learning effect. In this context, the learning diary was a required tool of documentation.

Another major part of the mentioned high learning effect is, besides the step by step learning and even more than the other competency-based learning techniques, based on the learning journal. As I have experienced, it is enormously helpful to bring both, the particular process steps and the connection between the various process steps, in mind. The importance of the learning journal arises from the fact that students often accomplish a task, but tend to not know precisely what they do and what the main connection between the tasks is. Finally, the reflection involving the creation of principles enabled me to summarize my lessons learned.

In conclusion, the practice of all the mentioned competency-based learning techniques has been a valuable
experience which helped me to keep the DE process steps easily in mind, especially with regard to future innovation issues.

4. Conclusions

Trying to use broader learning approaches than single loop learning is essential for the future dissemination of TRIZ. The momentousness of TRIZ for the development of systems – technological as well as societal – can be understood, if TRIZ is appreciated as more than just a technocratic toolset.

Ways of teaching TRIZ that support the deeper understanding of the methods and principles and also the understanding of their possibilities and relevance in changing thinking and last not least people should be enhanced in future.

The example described above shows the usage of a structured process, learning diary and learning journal as competency-based learning tools. The student’s perspective illustrates this and gives some insights in his work.

Regarding the grading of competency-based learning settings, a few specialties have to be considered. So the content (result of single loop learning) can be graded technically – the results of double loop and deuteron learning can only be graded regarding their taking place, their level of details, their deepness of reflection and so on – not regarding the result of the reflections being right or wrong!

This class now was given two times. The feedback of the students and the insights gained from the learning journals encourage the further development of this competency-based learning setting.

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References

Problem Solving Method of Standard Solutions under Analogy Thinking

Qiuyue Wang\textsuperscript{a,b}, Bojun Yang\textsuperscript{a,b,*}, Xiuling Duan\textsuperscript{a,b}, LiZhen Jia\textsuperscript{a,b}, Guozhong Cao\textsuperscript{a,b}, Jing Guo\textsuperscript{a,b}

\textsuperscript{a} School of Mechanical Engineering, Hebei University of Technology, Tianjin 300130, China
\textsuperscript{b} National Technological Innovation Method and Tool Engineering Research Center, Tianjin 300130, China

* Corresponding author. Tel.: +8613820270226; E-mail address: ybj@hebut.edu.cn

Abstract

As one of the tools of TRIZ, 76 Standard Solutions already have been widely used in product designing. How to combine analogy thinking and TRIZ, many experts and scholars have been put forward, such as primary and secondary analogy and so on. But it is only confined an idea put forward about standard solutions in combination with analogy thinking, there is no specific operational and process in detail. This paper proposes the use of analogy design thinking in the problem solving process with the Standard Solutions. Under the premise of the original problem-solving ideas with the standard solution, we can extract related properties of the specific case in base on the constraint condition, and then compare with the relevant attributes of each case of a standard solution. If exist similar properties, make the analogy. For example, a system is not allowed to change, which reflect to the case of the standard solution is immutable system. Get solutions by using analogy between the case of the Standard Solutions and the specific issues. Paper will verify the argument in detail and prove the feasibility of the theory in the use of clogging problems and lack of material in traditional feeding problems.

Keywords: Standard Solutions; Analogy design; Analogy; TRIZ; Su-F model

1. Introduction

As a development strategy of the current national, innovation-driven plays an important role in a fiercely competitive marketplace. Technological innovation is the concentrated expression of innovation driven in the enterprise. For innovation-oriented companies, if want to improve themselves in the competition, the key is product-innovation, and then realize technology innovation. The commonly used innovation techniques, namely the innovation idea generation methods, can be divided into two groups, which are intuitive and logical method. As well, as an innovative technique, TRIZ (theory of inventive problem solving) is the most representative one, which is suitable for application in the establishment. In the basis of researching a large amount of patents in various countries in the world, the theory of TRIZ is proposed by G.S.Altshuller and other people begin in 1946, which acts as a complete system to solve the creative issues. It is widely used in a variety of industries such as machinery, medicine, environmental protection and management occupations; it plays a key role in solving the concrete problem [1]. The core of this method is to answer the matters about the process of problem solving and support tools, which has been widely used in product design [2]. There are several tools to solve the question of TRIZ such as contradiction, resource analysis, evolution route and the standard solutions, in those methods, application of standard solutions to solve problem is the most characteristic in the process of innovation design, which on the basis of the Su-F (substance-field) analysis. Standard Solutions is a tool of solving innovation problems which is based on knowledge and is helpful to solve the problem of the third invention problem, namely, to improve the existing system fundamentally. The key of analogy designing is the connotation of analogical thought, which can reflect by finding the similarity between the existing products and the products to design. The relevant properties of existing products, directly or indirectly applied to design the product, design or improvement of products, realizing the innovation. The combination analogy design thinking and the Standard Solutions is primarily used in the
selection of the standard solution and in the process of solving problems with the standard solution. In the process there exist its related attributes and characteristics between each standard solution and its corresponding case. We can extract the features and match the characteristics of the specific question, and then analogy this features, in order to achieve the purpose to solve the related question. There exists a big breakthrough which is the extraction of the characteristic property in this process. This paper proposes the general process of standard solution in solving questions which is based on the combination analogy design thinking with the Standard Solutions.

Structure of the paper: in section 2 a principle of analogy designing is introduced. Section 3 introduces the definition and classification of the Standard Solutions. In section 4 a description of a new structured flowchart which is combination analogy design with Standard Solutions is presented. In section 5 an experiment which is used this method to solve is put forward. Eventually, section 6 explains conclusions and limits of the presented methodology.

2. Analogy design principle

Neither solve new problems nor create new things, we both need new products have certain attributes or characteristics, so the key is whether we can find other resolved with similar or identical attributes, in order to draw lessons from the reference and be applied to solve the existing matter. Thus, analogy design principle occupies a vital role in bringing new ideas. Analogy, namely the analogical reasoning, is to compare two substances that are different. According to the number of the same or similar attributes, speculate that these two things exists another modes of thought of the identical or semblable properties. In essence, analogy is a knowledge mapping from one to another area. The purpose of solving problem based on analogical reasoning is starting from the known practical situation of the target to achieve target goals, using the principle of similitude to a similar situation. Analog design based (ABD) is the analogy reasoning method applied to product designing [3], which can be applied in product innovation. Many specialists and scholars have done much research about analogy design method. For example, Bonnardel [4] thinks that the constrained cognitive environment will stimulate the designers’ inspiration to produce more new ideas in the process of analogy designing. And then McAdams etc. [5] studied the analogy design method which is based on the function similarity, and then the calculation method came up with based on function similarity and the operational steps are given concretely. In addition, Shai [6] perfected the analogy design on the principle of graphics similarity. The process of this mean is to establish a specific graphics according to the demand firstly which already exists in other fields about the graphics corresponding solution. We can replace the figure deformation with domain solution by analogy. Though the related literature is a bit less about the combination of TRIZ and analogy design, the most representative are two stages analogy-based conceptual design based on TRIZ [7] and creative design by integrating TRIZ and ABD [8].

Analogy design is divided into two types: transformation analogy (TA) and derivational analogy (DA). Transformation analogy transfers characteristics in the source design to the target design, such as part structure, component structure, principle and so on, which all can be used as the features to transfer, namely, TA transfers part of results in the source design to the object design. Derivational analogy delivers the process, method, activity, or scene in solving problem in the sources design to the target design, supporting the solving process of goal design for the solution, namely DA transfers some part of the solving process [3]. Cognitive psychologists believe that analogy consists of the following process: extraction; matching; assessment; abstraction; representation again. Extraction: the process of extraction is according to the scenario in working memory, through the similar sample in the long-term memory; Matching: this process usually appears between the source analogy and the target analogy in the working memory, we can characterize commonality by adjusting the structure, and then form the mapping inference form one to another structure; In the process of matching with the evaluation, evaluation of analogy and inference; In the process of abstraction, extraction commonality in the structure. Further processing is representation again, we have to be characterized again because the changing of match [3].

Thus, the key of analogy is finding the similarity between the target and the source design, then finding out the characteristics attributes of the object design. We can seek out the source which is close to the target through past experience or related areas, and then solve interrelated issues in the target projecting according to the way of figuring out the source problem.

Traditional analogy design principle is as fig.1: set the initial state and final state of source respectively is A and B, while the target design respectively is A’ and B’. There exists some relationship which we called β between initial state A and final state B of source design, β is the execution process or a series of operation, namely this can produce B if we build β up to A. It is known about the initial state of target design A’, but it’s unknown about the final state B’. There is some relationship β’ between A’ and B’, it can produce B’ if imposing β’ on A’. If there is some similarity α between A’ and A, so can determine β’ through β, then can confirm B’ through A’ and β’. In this process implied the similarity α’ between B and B’, lastly, B’ is the new design.

Getting the following analogy design thinking as fig.2 by linking the analogical thinking and the process of problem solving, the problem of original is defined as the target design in the course of solving equations, the retrieved related

![Fig.1. Process of analogy design](image-url)
cases referred to the source design. The premise of it is how to describe this case. It is necessity to describe clearly the problem before retrieving the similar cases which based on analogy. Then seeking out the source design by matching related cases in the big database which based on similarity, mapping, lastly, we can obtain the solution to the issues.

3. The Standard Solutions

Substance-Field analysis is the simplest model in describing the problem in TRIZ. The same as inventive principles, technology evolution theory, and effect, Standard Solutions also is an applied tool based on knowledge in TRIZ. It describes the problem in constrained conditions which makes the question standardized, by this way, can solve the technology contradiction in TRIZ, reaching the goal of obtaining understanding solution of high level. Standard Solution is the rules of comprehensive and transformation about problems, its purpose is to overcome or avoid the technical contradiction and physical contradiction. Therefore, using the Su-Field and 76 Standard Solutions to solve questions will simplify the process of analysis problem and save time in working out. As one of the tools of trouble-solving, Standard Solutions is divided into five types which is a total of 76[9]. The specific classification is as follows in table 1:

Typically, the 76 Standard Solutions are used as a step in ARIZ, after the Su-F model has been developed and any constraints on the solution have been identified. The model and the constraints are used to identify the class and the specific solution. As in other TRIZ instructional material, examples are used to show the applicant of the Standard Solutions to a wide variety of problems from many fields [9]. The solutions in classes 1-4 frequently make the system more complicated, since many of them require the introduction of new materials or new fields. The solutions in Class 5 are methods for simplifying the system, making it more ideal. After deciding on a solution from classes 1-3 for a performance problem or class 4 for a measurement or detection problem, use class 5 to simplify the solution. See Figure 3 [10] for a flowchart showing in more detail the use of the various classes of the 76 standard solutions for both problem solving and technology forecasting.

The flowchart of the Standard Solutions is very concrete and the steps lay out are overwhelming, making the designers usually waste a lot of time to find out what kind of Standard Solutions for specific solution to match, so there needs an improvement about the convenience of the given problem. In addition, the particular Standard Solution is more general, needing especial analysis corresponding to the certain...
question, such as adding additive, etc. Considering featured constraints for given issues, you can have the specific description and analysis from this hand.

4. The Standard Solutions combined with analogy design

In product innovation, the analogy design is becoming an increasingly important method of bringing out new ideas and innovation solutions and ways. Analogy is a way to solve new problems which according to the similar problems have solved solution which is based on past experience. TRIZ combined with analogy design applied to product improvements have been put forward by many experts and scholars, but there is only some simple theory and no detailed introduction of the application of the actual about the Standard Solutions combined with analogy design. Analyzing the process of Standard Solution with the application of analogy design thinking helps more effective use of Standard Solutions to solve the problems of different innovative design. As a way of thinking, analogy design is applied to the course of trouble resolution which using the Standard Solutions, during the process the key is to find the similarity between a Standard Solution and the features of problems. So that can find the especial solution of the given questions which is convenient to come out answers. The particular flow chart is as fig.4:

Step 1: analyses the given specific problems which we called it is pre-treatment, such as artificial cut or selected by network system, to extract the characteristic properties and constraints of the problem.
Step 2: determine the extracted attribute belongs to which property, resource properties or parameter properties or structure attribute, structure attribute namely physical attributes + field attributes, if there exist two kinds of material and field namely exist structure attributes, then you can analysis the problem with the Su-F model, then set up the Su-F model of this system.
Step 3: analyses the purpose of the problem to direct analogy, and then classify the questions to three models which are reduce harmful effect, strengthen the Su-F model and the insufficient effect which the model belongs to, and then parallel to the corresponding one kind of Standard Solutions.
Step 4: find out the one or a few Standard Solution and the related cases which is equivalents.
Step 5: analyses the related resources and the available resources in the environment and analogy the parameter properties in the available resources or the related cases, deciding which resource can realize the purpose of the problem and conclude the analogy solution. If there are unavailable resources, you have to find out the corresponding Standard Solutions which are matching, looking for the solutions.
Step 6: put forward the analogy solution, then evaluation of the solving method, making the problem-solving approach implementing.

The key is to extract feature parameters in combination Standard Solutions with analogy design. The key point is the parameter properties extraction in the case.
The process of analogy design in specific problem is as fig.5.

5. The engineering examples

In the field of metallurgy and chemical industry production, companies often use feeding equipment to transport the powder, dry granular materials and wet materials after filtration and dehydration, from bin or the under hopper to the other equipment and dry or washing equipment. For dry materials and the wet that has well liquid, we often use disk feeder or star feeder which is generally won’t produce blockage or blanking not smoothly; the materials, which have higher liquidity and humidity less than ten percent, will have some problems about hanging the wall, arching bridge and congestion before entering the dryer.
According to the above steps, we can look for a solution of the issue.
Step 1: pre-processing of the problem (establish the functional model of the system)

The system model before the problem appearing is as fig. 6:

Through the model established in fig.6, we can find the key of this question is between feeding equipment and materials. The description of the problem is to solve the blocking, hanging the wall and the sticking problem of the traditional feeding equipment. The main parameter property is the blocking, hanging the wall and the sticking trouble, namely is the matter of excess materials residues.

Step 2: feeding equipment+ material, the interaction between them is resistance, which belongs to the structure properties, can be solved by Su-F model.

Step 3: analyses the purpose of the issue to conduct direct analogy.

The purpose analogy, namely the ideal solution is as fig.7.

①The Su-F model of the problem areas is in fig.8.
②This matter belongs to the insufficient effect, corresponding to the corresponding Standard Solutions.

Step 4: find the corresponding one or a few Standard Solutions and find out the related cases.

We can define the problem as the excess material residues problem that can be solved by changing the Su-F model. Select NO.15 (Double Su-Field Model: A poorly controlled system needs to be improved but you may not change the elements of the existing system. A second field can be applied to S2) as a general solution.

Step 5: analyses the available resources in the environment, and then record it.

If the resources are unavailable in the environment, we can correspond to the corresponding Standard Solutions to get the solution.

The case of the corresponding Standard Solutions is the problem of the electrolyte residue in the copper surface.

Step 6: get the solution of the problem. The process of this problem is as fig.10.

We can solve the problem of hanging the wall, arching bridge through vibration, the same, can solve the problem of lithium carbonate with feeder have a good contact, to a certain extent, can solve the congestion problem through vibration.

In solving the problems of using Standard Solutions in the past, step one, step two and step three is the same as the above. Su-F model of this question belongs to the type – inefficient model. Choosing Standard Solutions, experts or abecedarians will take nine parts to consider which are adding an internal additive, adding an external additive [9], utilizing the environmental resources, changing the environment, controlling small quantities, taking advantage of the medium, protecting the local, chain Su-F model and double Su-F model, in lead to spend much time and energy, all the same, would like to choose the wrong answers. Taking this way which is mentioned in this paper, meanly combining the analogy thinking with Standard Solutions, enterprisers will save many hours and reduce the fallible rate.

Through this paper put forward this method, there still are something to improve, such as the details which remains to a further research and the specific research which remains to further introduce.

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References


Abstract

The Internet of Things (IoT) is the network of physical objects or “things” embedded with electronics, software, sensors, and connectivity to enable objects to exchange data with the production, operator and/or other connected devices. IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration between the physical world and computer-based systems, and resulting in improved efficiency, accuracy and economic benefit.

The important factors in the world of IoT are the technologies supporting products, the main functions of the technologies and the efforts for value-enhancing of these functions.

In this study, IoT was analyzed based on TRIZ. The Law of Technical System Evolution was studied from the view of the Function Analysis. Also, the core value of IoT was analyzed based on the Function Analysis. Finally, the future technologies that could enhance the value of IoT were forecast.

Keywords: TRIZ; IoT; Law of Technical System Evolution; Function analysis

1. Introduction

Internet and mobile revolution have changed our lives and thinking recently. IoT is the next generation of smart communication, which connecting everything to communicate with each other even objects, systems, and human beings.

The IoT market has a current value of US$308 billion and an 11.9% compound annual growth rate (CAGR) forecast to 2015, otherwise US$3.8 billion and a 26.6% in Korean market, as shown in Fig. 1 [1]. Fig. 2 shows that Apple, Nest, Google, and other IT companies are already challenging the IoT market [2]. Therefore, we have to predict the future trend of IoT and prepare how to cope with this market through any systematic methodology such as TRIZ.

TRIZ includes a practical methodology for generating innovative solutions for problem solving. IoT also can be analyzed based on TRIZ by applying some kinds of laws and principles in TRIZ. For example, the Law of Technical System Evolution could be applied to predict the most likely improvements that can be made to a given product. This is because several trends can be discovered by the Law of Technical System Evolution - the way technical systems have been developed and improved over time.

In this study, IoT was found to have followed the Law of Technical System Evolution in TRIZ, which was proved based on the application of TRIZ on a smart car system.

2. TRIZ and IoT

There are three common elements or features for IoT(Fig.3)[3].

- Intelligence
- Connectivity and Communication
- Novel Value Providing

These features of IoT can be explained very well via TRIZ and there are many correlated factors between IoT and TRIZ.

The first feature – Intelligence – is almost same as the Law of System Completeness, which is one of the Law of
Technical System Evolution. Any working system consists of four principal parts: working means (tools), transmission, engine and control units. The engine generates the needed energy, the transmission guides this energy to the working unit, which ensures contact with outside world (processed object), and the control units makes the system adaptable. Among these units, the control unit could be regarded as the Intelligence as shown in Fig. 4.

The second feature – Connectivity and Communication – can be explained by the Law of Energy Conductivity in System and the Law of Coordinating Rhythms of the System Parts. The objects or systems in IoT use the wireless communication for the shortest path of energy delivery. This is exactly correspondent that the technical systems evolve in the direction of shortening of energy flow passage through the system. In addition, the wireless communication with the same frequency band is used to make harmony of rhythms of each others.

Finally, the Law of Transition to the Super System can be adapted to the Novel Value Providing. Although IoT is the connections just between products and human beings at the early stage, the connections would become the ultimate networking systems for whole world as shown in Fig. 5.

As shown in the above relationships, IoT was found to follow the Law of Technical System Evolution.

3. Case Study

In the several major promising industries of IoT – health care, wearable, smart home and smart car, the Law of Technical System Evolution can be applied to smart car system as shown in Fig. 6. The future of smart car could be predicted based on the above three common features of IoT – Intelligence, Connectivity & Communication, and Value Providing.
Fig. 6 Four major promising industries of the internet of things

**Smart Home**
- Automatic housing management
- Connections between consumer electronics products, security

**Smart Car**
- It is convenient to the use of motor vehicles
- Real-time detection of automotive performance

**Health Care**
- Biological signal inspection
- Transmission of health information
- Remote medical care

**Smart City**
- Real-time information of the road
- Traffic safety control

Smart car system has become a novel system by adapting the electrical field with the mechanical field, which consists of main body, transmission mechanical and electrical, engine, and control system as shown in Fig. 7. As the system becomes more complex and integrated, the intelligent control system will be evolving as based on the Law of System Completeness.

Connectivity & Communication is the second feature of IoT. The Law of Coordinating Rhythms of the System Part can explain that the smart car will be able to sense and analyze the rhythm of surrounding other smart cars not to collide each others. Some examples are shown in Fig. 8 and 9. Also, smart car will be activated by recognizing drivers’ fingerprint or iris, which is almost same the Law of Energy Conductivity.

From the view point of the Novel Value Providing, the Law of Transition to the Super-system can be applied, which means that technological systems evolve from mono-system to bi- or poly-systems. Smart car will be able to communicate with right next one, surrounding ones and moreover with all of the smart cars in the world. Also, we can expect the smart car to be controlled by the acoustic field, for example human voice, rather than the electric or mechanical field. This means the Law of Increasing the Su-Field Involvement can be applied to predict the future of IoT.

Fig. 7 Smart car system

Fig. 8 Smart car and smart control device (Apple)

Fig. 9 Virtual Tow (Honda)
Fig. 10 shows that it is prerequisite to be careful of contradictions when predicting the future of IoT. For example, if there is a convenience, security is vulnerable. On the contrary, it is necessary to abandon the convenience in order to enhance the security. It is possible to introduce the iris or fingerprint that can have security and convenience at the same time.

4. Conclusions

IoT has becoming a new technology and has three common features that are explained by TRIZ. Intelligence can be analyzed by the Law of System Completeness. Connectivity & Communication was exampled by the wireless communication of the shortest path of energy delivery and the harmony of rhythms of the parts. New value can be provided more widely by incorporating the multiple connections.

Smart car system was following the Law of System Evolution. The analysis and solutions for the contradictions in IoT should not be ignored. All of the laws regarding TRIZ can be useful to predict the future of IoT.

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Directed Evolution® - an update after a decade

Boris Zlotin, Alla Zusman *

Ideation International Inc, 32000 Northwestern Hwy, STE 145, Farmington Hills, Michigan, 48334, USA

* Corresponding author. Tel.: +1-248-613-9787; fax: +1-248-960-1564. E-mail address: azusman12@ideationtriz.com

Abstract

The Directed Evolution (DE) technology is an application and an extension of the Theory of Inventive Problem Solving (TRIZ). It was introduced and has been in development since the early 1990s by Ideation International’s research group as a pro-active approach to the evolution of technology. Instead of making a prediction and waiting for it to be confirmed, the DE process uses numerous patterns and lines of evolution for the purpose of identifying possible scenarios, selecting the most promising ones, then- building a road map and planning the process of implementation. In other words, DE is a method to predict future generation of a system by inventing it. To date, DE can be applied to various aspects of human life, including product and process development, evolution of technologies, markets, organizational development and more.

Later, significant progress has been made with the introduction of Directed Evolution® software, which incorporated powerful analytical tools and substantial knowledge base for predicting and solving various problems and more.

In 2006 the authors presented a paper at the ETRIA conference on DE demonstrating the possibility and the benefits of the purposeful management of the further development of various systems, including but not limited to products, processes, technologies, organizations, and social systems. The proposed paper addresses selected latest findings and practical results in the given area and possible directions for further development of the methodology.

Keywords: TRIZ; Directed Evolution; neural networks; Artificial Intelligence; innovation; technological forecasting.

1. Introduction

Directed Evolution (DE) technology is a result of integration and further development of Technological Forecasting [1, 2] and the Theory of Inventive Problem Solving (TRIZ) [3].

Technological Forecasting was introduced in the mid-1950s as a collection of non-related techniques based on probabilistic modeling of future characteristics of various systems. While proven being useful for short-term predictions, the method failed to deliver reliable long-term results, primarily due to the tools that were utilized to develop the forecasts.

By the mid-1970s, the discovery of Patterns of Evolution has enabled the introduction of TRIZ Forecasting. Unlike traditional technological forecasting, it is based on utilization of pre-determined patterns offering new directions together with proven ways of their realization. However, while providing valuable insight on the nature of the next generations of the given systems, TRIZ Forecasting couldn’t provide reliable answers as to when these new generations would come to existence.

The Directed Evolution (DE) was introduced and has been in development since the early 1990s by Ideation International’s research group as a pro-active approach to the evolution of technology. Instead of making a prediction and waiting for it to be confirmed, the DE process uses numerous patterns and lines of evolution for the purpose of identifying possible scenarios, selecting the most promising ones, then- building a road map and planning the process of implementation. In other words, DE is a method to predict future generation of a system by inventing it.
During the last 20 years, the authors have described the method, the process and selected practical results in the book [4] and in the number of papers [5-11], including the paper presented at the ETRIA conference in 2006 [12]. Specifically, this paper included brief descriptions of four selected predictions related to information technology, in particular:

- Paperless technology
- Personal assistant (Alter Ego)
- Digital and analog hybridization
- Global safety and informational transparency

The audience mostly perceived the above as fantasies, given that at that time their realization was hindered by the absence of necessary technical means. Today, approximately a decade later, the situation is quite different.

Regarding paperless technology, the description stated that “recently developed technology will soon bring forth special “screen glasses” to provide contrast and a high resolution, 180-degree view, giving people a comfort that is comparable with reading from paper. Most children today grow up around computers, making human-computer interaction completely natural. Other new technologies, such as computer dictation and mental and voice computer control, also contribute greatly to the upcoming transition to paperless technology”. Although today Google glasses are still in the infancy and have strong competition from various tablets and e-readers, the “screen glasses” represented the first wearable devices which are on the rise currently and may impact the scenery.

At the same time, the most exciting development that has taken place recently providing the means for the realization of the other three predictions (and much more) is described below. The main lesson here is that anything that is desirable and feasible will be realized sooner or later.

2. Brief description of the DE history and evolution to date

1975-1992

In the spring of 1975 Genrich Altshuller, the founder of TRIZ, distributed among TRIZ schools a manuscript with the first set of Patterns of Technological Evolution [3]. In the beginning of 1976, Boris Zlotin began teaching a course on the Patterns of Technological Evolution to the students at the St. Petersburg People’s University for Technical Innovation (SPUTI). Because of the limited theoretical material, the education was focused on attempts to apply it to further development of various technological systems resulting in numerous promising inventions for the systems without obvious problems. Furthermore, it became quite obvious that the patterns of evolution could be used for technological forecasting. In the early 1980s, Boris Zlotin and Alexander Selutskiy conducted the first comprehensive long term TRIZ forecast (with the utilization of all known patterns at that time) for the timber industry as a part of TRIZ project for a large wood and paper producing company. The prediction results have been rejected by the Subject Matter Experts from the industry R&D center; however by 1995 over 50% of suggested ideas have been realized (we estimate that by now it should be around 70-80%). The full scale TRIZ forecasting projects for industrial companies followed, being conducted by Vladimir Petrov (evolution of electrical welding), and the team lead by Boris Zlotin and Svetlana Visnepolschi conducted the project on evolution of immersed pumps.

The TRIZ forecasting project for immerse pumps was funded by the grant from the government (a special program for encouraging innovation in the former Soviet Union). The group included 5 TRIZ specialists and trainees with the contribution of several dozens of various Subject Matter Experts. The project continued for over 3 years, including parallel utilization of TRIZ and methods of classical technological forecasting, in particular Delphi method (5 iterations), trend analysis, S-curve analysis, analytical modeling, morphological analysis and other recommended techniques [1, 2].

TRIZ part of the project included:

- Analysis of the system’s prior evolution and patents, revealing the main problems and contradictions in the process of evolution, unresolved problems (or partially resolved ones) at that time.
- Analysis of the evolution of the super-systems, including marketing requirements and government regulations, identifying driving forces of evolution and formulating problems associated with limitations imposed by various super-systems.
- Analysis of cause-effect relationships within the given system and with the super-systems and formulating problems addressing insufficient, absent or undesired connections.
- Utilization of patterns of technological evolution, identifying missed and expected future steps in the evolution of the given system and formulating problems associated with their realization.
- Conducting Failure Prediction for the purpose of revealing and analysis of potential undesired scenarios and formulating problems to be solved to avoid them.
- Solving formulated problems using TRIZ tools.
- Identifying possible critical conditions and crisis points that must take place to ensure the emergence of new generations of the given system.
- Formation of the road map with the alternative scenarios and selection of the most desirable one among them.
- Second project iteration – repeating the steps 1-8 to check for additional potential benefits and/or undesired events based on results obtained so far.
- Building the final road map around the selected scenario targeting its realization together with recommended strategies for the conditions of stable before-crisis, crisis and post-crisis development.
- Developing the system for the comprehensive IP protection and building the system for monitoring the further development allowing to introduce correction in the cases of significant changes of plans and/or events beyond control, for example, new scientific discoveries, political changes, etc.

The project resulted in detail description of the future evolution of pumps with over 30 patentable solutions. Unfortunately, political changes in the Soviet Union in the end of 1980s and early 1990s didn’t allow the implementation of
project results, thus preventing their publication and patents filing. However, our own follow up for the next 30 years has shown that the predictions made with the methods of traditional technological forecasting failed while the ones obtained with the use of TRIZ have mostly been realized.

Other positive scientific results of the above project were as follows:

- Revealing the most basic differentiation of TRIZ forecasting versus traditional technological forecasting as follows:
  - Traditional forecasting is focused on predicting certain events and/or certain system’s parameters and time of their realization, without specifying the ways by which they could be achieved
  - TRIZ forecasting is focused on revealing problems and obtaining specific solutions providing the given system improvement and further evolution. In this case, implementation time depends on various often random factors; however, it gives an opportunity to a person or a company to take charge and use the results to get ahead of competitors

- Proof of the applicability of TRIZ tools on all stages of the project and high effectiveness of Failure Prediction method (Zlotin, 1978 and Visnepolschi, 1982), and Scientific Problem Solving (Zlotin, Zusman, 1985).

- Formulation of two additional patterns of technological evolution and development of the patterns new structure in replacement of the system originally suggested by Altshuller that included the following 8 patterns [13]:
  - Stages of evolution (infancy, growth, maturity and decline)
  - Evolution toward increased ideality
  - Non-uniform development of system elements
  - Evolution toward increased dynamism and controllability
  - Evolution toward increased complexity followed by simplification
  - Evolution with matching and mismatching elements
  - Evolution toward micro-multi-levels and the increased use of fields
  - Evolution toward decreased human involvement

- Establishment of the matrix-type structure of sub-patterns, or lines of evolution, including general lines of evolution and specific lines of evolution for different areas of applications

- Over 20 additional lines of evolution have been developed and published in 1989 [14]

- Development of a detail list of questions to be answered in the process of TRIZ forecasting

- Formulating the concept of the practically exhaustive set of alternative ways of system’s evolution and proving the possibility to do it

- Formulating the necessity to account for mutual influence of technological and business evolution in the given area

- Refining the technique for selecting DE project participants and the minimal volume of training necessary to ensure effective work.

Overall, this project has solidified the term TRIZ forecasting that later was replaced with the term Directed Evolution to reflect the important transition from passive attempt to predict “what could happen” to the pro-active approach of directing the development toward desired results.

While political changes in the former Soviet Union in the end of 1980s – early 1990s didn’t allow fully capitalizing on the project results via its realization, further development of TRIZ forecasting was continued by the company Progress, the first TRIZ-based commercial company in the world established by the members of Kishinev TRIZ School. Between 1986 and 1992 the following important pieces of the methodology have been developed:

- Methods of analysis of cause-effect relationships (Zusman, 1989) that later was utilized in development of computerized module Problem Formulator allowing to build a graphical diagram of these relationships and automatically “slice” a complex situation into standardized types of Directions for innovations (solutions) with the corresponding sets of standardized recommendations (operators) and/or lines of evolution to obtain actual solutions. Besides expected results, additional unexpected benefits of the approach were as follows:
  - For smaller “slices” of an innovation situation, quite often conventional engineering knowledge and practice are sufficient for obtaining high-quality innovative solutions.
  - “Slicing” of the innovation situation almost always would unveil directions that haven’t been considered while being rather easy to pursue.

- A set of about 270 operators for solving inventive problems

- Over a hundred of new lines of evolution

- Enhanced DE questionnaire

When the general economic situation in the former Soviet Union began deteriorating, a need for Express TRIZ forecasting became evident. In this case, instead of aiming to obtain a practically exhaustive set of evolutionary alternatives, the projects were focused on obtaining a limited number of promising concepts sufficient for providing the customer with a certain competitive edge. Express TRIZ forecasting projects were completed for various customers, including metallurgical company, three aviation production plants, a plant producing military tanks and railroad cars, and others. In parallel, software development to support inventive problem solving and TRIZ forecasting were launched.

1993-2012:

In the end of 1992, Ideation International Inc. was established in the U.S. by the co-founders of Progress and American partners. Within the next several years, Ideation has acquired intellectual property of Progress and started sponsoring further development of TRIZ forecasting that was soon renamed into Directed Evolution, one of the applications of the Ideation Office of Innovation.

During the last two decades, the theoretical foundation of DE has been substantially extended [5-12] accompanied by the development of the corresponding DE software, now including the following modules [15]:


• Psychological preparation to the DE project based on the Creative Imagination Development techniques
• Enhanced questionnaire, equipped with instructions and illustrations
• Problem Formulator®
• Over 500 lines of evolution
• About 600 operators for solving inventive problems
• Failure Prediction and Failure Analysis
• Evaluation and further enhancement of obtained innovative concepts
• Estimation of technical and marketing value of inventions and/or projects
• IP Management suite, supporting:
  ○ Invention enhancement
  ○ Design (inventing) around and protection from design around
  ○ Completion of invention disclosures
• Express DE
• Monitoring DE results

Over the last two decades, Ideation has completed 52 projects for various industries and clients (38 full size and 14 Express DE projects, including automotive, chemical, oil and gas exploration and production, solar panels, energy, waste management, medical instrumentation, food production and other industries. It has also developed educational materials and conducted series of DE workshops in the U.S. and Japan. As a result, several dozens of individuals have been trained and certified in DE application. Each DE project (especially full size ones) required collection and analysis of significant amount of information, with time, besides hundreds of additional lines of evolution, rather substantial DE knowledge base had been accumulated that was named the Bank of Evolutionary Alternatives, including dozens of predictions made at different times, many of which have been already confirmed (see selected predictions in the Appendix).

3. Future of DE application and software

3.1. New enabling technology – P-network based Artificial Intelligent systems

As it was mentioned earlier, one of the main reasons that made the participants of our ETRIA 2006 skeptical of the DE presentation describing several possible predictions was the absence of means for their realization, in particular, reliable and highly capable Artificial Intelligence systems. This situation changed in the end of 2012 when we were approached by our former TRIZ student Dmitri Pescianschi.

In 1990 Dmitri, a high school student at that time completed with flying colors the 220-hour TRIZ education seminar provided by Progress for engineering professionals. Later after becoming the software developer, he utilized TRIZ to get around the limits established (and mathematically proven) in 1969 by MIT professor Marvin Minsky, the highest authority in the areas of neural networks and artificial intelligence, declaring fast training and stable operation of large neural networks technically impossible. As a result, Pescianschi has built five working prototypes proving his approach. For example, tests have shown that the product developed by Progress and named P-network could be trained with 7000 images 3350 times faster than available on the market neural network IBM SPSS Statistics 22 (tests are provided on the same computer). Moreover, when the number of training images is higher, IBM SPSS Statistics 22 freezes completely, while Progress P-network is trained with 100,000 images within about a minute. The first patent application on this invention is filed, more applications are in the making, the first scientific papers are accepted to be published [16, 17].

Breaking the neural network training speed barrier opens the possibility for practically unlimited number of applications, including highly efficient and reliable voice, image and pattern recognition in real time mode, enabling various AI-based devices, including but not limited to smart personal assistants. However, for the purpose of this paper, we would like to emphasize the fact that it is possible to use intelligent p-networks for radical enhancement of the methodology and software supporting innovation activities.

3.2. Future of the DE application and software with the utilization of P-network based AI

We have conducted the Express DE project for the purpose of identifying possible future of DE application and software with the utilization of P-network based AI.

For DE software, this combination will allow for the realization of interactive human-machine mode of operation, including:
• Game-like psychological preparation to the DE project
• DE questionnaire module capable to conduct preliminary analysis of the inputs and ask additional question, conduct associative search on the Internet in the “Software agent” mode, evaluate the relevance of the inputs and their significance for the given project
• Automatic Problem Formulator capable of the following:
  ○ “Discussion” of cause-effect diagrams with the user
  ○ Intelligent selection of relevant operators and lines of evolution and their best combinations to ensure successful results
  ○ Self-learning and accumulation of experience in the process of interaction for better adaptation to a particular user and the given task
  ○ Self-improvement in the process of work as the user enters new information and new ideas
• Concept evaluation and enhancement module capable to guide the process suggesting variants for enhancement
• Set of evolutionary lines and operators adapting to the given project, including the ability to generate recommendations based on obtained ideas with the context specifics
• Failure Analysis module helping find reasonable explanations for unknown causes of failures
• Failure Prediction module checking the obtained ideas for potential problems and dangers
• IP protection module facilitating the best possible protection and continuously monitoring information to detect possible infringements of patents
• Module monitoring the post DE environment, automatically searching and detecting critical events capable to impact implementation plans
• Adaptation of DE training materials to a specific trainee, taking into consideration his/her knowledge, experience, style of learning, etc.
• Internet-based continuously updated bank of Evolutionary alternatives

3.3. Potential business and social benefits and dangers

We also expect the following impact to the overall technology, business and society that should be taken into consideration while conducting DE projects, especially the full size ones:
• As the first step, radical impact on all informational technologies and complete change of computer industry
• Changes expanding to other technologies
• Parallel changes to the business environment. For example, P-network based systems are capable to effectively evaluate economic conditions, provide process optimization, assist in trading forecasts, etc.
• The process above will be followed by social and cultural changes, for example, in the areas of education, healthcare, entertainment and others. It will also facilitate the process of introducing “electronic democracy” based on accounting not only for each vote but also for the competency of the voters in every particular referendum thus reducing the impact of bureaucracy in social and political life.

It is well known that any positive change is associated with possible negative ones, and unintended consequences could be especially dangerous. While conducting Express Failure Prediction as a part of the project, the following potential dangers have been identified:
• The entity that will be the first conducting and implementing the results of DE project in the given area will have great chances to become a monopoly
• DE+AI complex will inevitably originate crises in various areas, impacting the overall economic environment and eventually make the existing patent system inadequate
• DE + AI successes will amplify the fears of robots dominating the human world as “electronic dictators”

At the same time, the things indicated above and alike are really dangerous if they take the world by surprise and without proper control, which could be prevented with the use of the same newly arising technology and with adequate economic and political measures.

4. Conclusions

• In the informational era, the TRIZ problem-solving methodology is transforming to the next stage – Directed Evolution®, a pro-active approach to the guided evolution of various systems, both technical and non-technical.
• The Directed Evolution method has been applied to numerous areas allowing for certain predictions, some of which have been already realized.
• DE software besides embedding DE process which guides the user through, has become an invaluable bank of the cross-discipline knowledge to tap to while generating novel ideas
• In the future, one should expect from the combination of DE and the P-net based AI the following advantages:
  ○ Next generation of highly interactive DE software and its application
  ○ Radical impact on all informational technologies followed by changes in other technologies and eventually, in cultural, social, economic and political environment

Potential dangers and unintended consequences should be addressed with the use of DE+AI technology to ensure smooth and crisis-free transition.

References

Appendix. Selected Predictions

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Confirmation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994: Printing patterns on car exterior</td>
<td>2010; Smart cars USA Today 07.07.10</td>
</tr>
</tbody>
</table>
  
  2001: Volvo started experiments, proved customer satisfaction and critical increase in safety 
  
  2010: Japanese inventor Masuyuki Naruse built a prototype (patented in 1992) |
| 1994: Super-maneuverable watercraft repeating evolution of skies and skates, 
  watercraft polo and other games etc.                                    | 2010: Super- maneuverable motor boat                                                                                                                                                                          |
| 1995: Mobile phone combining functions of telephone, garage remote, bank 
  information, electroshock device, etc.                                  | 2002: Smart phone with credit card abilities                                                                                                                                                                 |
| 1995: Cell phone without cellular towers                                 | 2010: Cell phone without cellular towers                                                                                                                                                                    |
| 1998: Mobile fueling vehicle to serve cars and trucks at large parking 
  lots                                                      | 2010: New service at some airport parking lots: fueling and small simple service                                                                                                                                 |
| 1999: Waves of safety in automobiles predicted the next drop in safety   | 2009-2010: Various publications on problems in Toyota’s automotive                                                                                                                                            |
| 1999: Ethanol to become the best alternative fuel                        | 2008-2009: Increased production of ethanol in  
  
  2010: Japanese inventor Masuyuki Naruse built a prototype (patented in 1992) |
| 1999: Waves of safety in automobiles predicted the next drop in safety   | 2009: An attempt to tax sugary drinks in New York  
  
  2000: Obesity is a result of addiction. Producers of highly addictive food will be treated like tobacco companies  
  
  2001: Volvo started experiments, proved customer satisfaction and critical increase in safety 
  
  2010: Japanese inventor Masuyuki Naruse built a prototype (patented in 1992) |
| 1995: Cell phone without cellular towers                                 | 2010: Cell phone without cellular towers                                                                                                                                                                    |
| 1998: Mobile fueling vehicle to serve cars and trucks at large parking 
  lots                                                      | 2010: New service at some airport parking lots: fueling and small simple service                                                                                                                                 |
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| 1999: Ethanol to become the best alternative fuel                        | 2008-2009: Increased production of ethanol in  
  
  2010: Japanese inventor Masuyuki Naruse built a prototype (patented in 1992) |
| 2001: Ethanol production from Algae                                      | 2009: Algenol Biofuels, Dow Chemical consider ethanol production from biofuel. Exxon Mobile is looking into synthesis of oil from Algae. USA Today 07/30-09 |
| 2004: Food will be evaluated not by fat, carbs, or calories but by its level of addictiveness | Still in discussion  
  
  2005: Animal military application  
  
  2004: Wallport – a system automatically ordering and delivering produce to homes |
| 2005: Animal military application                                        | Article in ‘USA today 07/30-09  
  
  2004: Wallport – a system automatically ordering and delivering produce to homes |
| 2004: Wallport – a system automatically ordering and delivering produce to homes | Partial confirmation - Article in USA today 08/09-12  
  
  2006: Hybridized solar panel with rechargeable battery |
| 2006: Hybridized solar panel with rechargeable battery                   | 2014: Low cost and high efficient rechargeable hybrid solar battery for different applications. Press release, Ohio State University |
| 2000: Obesity is a result of addiction. Producers of highly addictive food will be treated like tobacco companies | Law suit against McDonalds by obese people.  
  
  2001: Volvo started experiments, proved customer satisfaction and critical increase in safety 
  
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Validation of Kando Requirements in the Kando Understanding Support Process Using a V-model

Eisuke Saito\textsuperscript{a*}, Satoshi Takezawa\textsuperscript{b}, Hiroshi Hasegawa\textsuperscript{a}

\textsuperscript{a}Shibaura Institute of Technology, Fukasaku 307, Minuma-ku, Saitama-shi, Saitama 337-8570, Japan
\textsuperscript{b}TOSHIBA Elevator and Building Systems Co., Japan

\textsuperscript{*} Corresponding author. \textit{E-mail address:} mf15031@shibaura-it.ac.jp

Abstract

Understanding customer requirements is most important for conceptual design. Through the Kando experience, successful companies are able to achieve customer satisfaction by providing the highest quality service. The Idea Creation Support System (ICSS) has been developed for idea creation via the Kando Understanding Support Process which includes Word Of Mouth (WOM) effectiveness. This study’s objective is to develop an ICSS assessment system, including quality assurance in order to create attractive product ideas based on a V-model with Verification & Validation (V&V). Because ICSS’s Kando Understanding Support Process depends heavily on the human mind and emotion, in this paper, we propose an ICSS assessment system validation process consisting of the Taguchi Method (TM) and Functional Near-Infrared Spectroscopy (fNIRS) bioinstrumentation. Particularly, this process was applied to idea creation for an attractive new vacuum cleaner. Using fNIRS measurements, our results confirm that this process is desirable for creating an idea for which subjects will have positive expectations (i.e., positive emotional reactions), satisfying Kando requirements.

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\textit{Keywords:} V-model; V&V; Conceptual Design; Kando Understanding Process; Taguchi Method; fNIRS

1. Introduction

Understanding customer requirements is most important for conceptual design. Successful companies provide the highest quality service, by which customers receive satisfaction through a Kando experience. Thus, customer satisfaction through their experience is necessary for greater success in business. From this background, many researchers are studying methodologies for understanding customer requirements\textsuperscript{1-6}. For example, Chen et al. edited the “Special Issue: User Needs and Preferences in Engineering Design” on ASME Transactions, Journal of Mechanical Design\textsuperscript{1}; Moreover, Sato and Hasegawa have proposed the Idea Creation Support System (ICSS) including the Kando Understanding Support Process through WOM communication effectiveness\textsuperscript{7,8}.

\textbf{Nomenclature}

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ICSS</td>
<td>Idea Creation Support System</td>
</tr>
<tr>
<td>WOM</td>
<td>Word Of Mouth</td>
</tr>
<tr>
<td>V-Model</td>
<td>A Popular development model for Systems Engineering processes</td>
</tr>
<tr>
<td>V&amp;V</td>
<td>Verification &amp; Validation</td>
</tr>
<tr>
<td>TM</td>
<td>Taguchi Method</td>
</tr>
<tr>
<td>fNIRS</td>
<td>Functional Near-Infrared Spectroscopy</td>
</tr>
<tr>
<td>QFD</td>
<td>Quality Function Deployment</td>
</tr>
<tr>
<td>CDSS</td>
<td>Creative and inventive Design Support System</td>
</tr>
<tr>
<td>DOE</td>
<td>Design Of Experiment</td>
</tr>
<tr>
<td>oxy-Hb</td>
<td>Oxygenated haemoglobin</td>
</tr>
<tr>
<td>deoxy-Hb</td>
<td>Deoxygenated haemoglobin</td>
</tr>
</tbody>
</table>
Kando has been explained as “A mind moves through deep feelings about things” in the Kojien (the most famous Japanese dictionary, published by Iwanami). Sato and Hasegawa have defined Kando in detail using emotional design theory\(^9\) and the Attention Interest Desire Experience Enthusiasm Share (AIDEES) model\(^10\) for consumer behaviour understanding\(^7,8\). This paper explains their outline of the Kando definition as follows. First, according to Norman’s emotional design theory\(^9\), human response characteristics have been shown to be caused by three levels of brain function, i.e., the visceral, the behavioural, and the reflective. Specifically, the visceral level is related to first impressions, the behavioural level is related to feedback such as joy or happiness attending surprise concerning a product’s use-experience, and the reflective level is concerned with satisfaction acquired from owning or using a product over a protracted period of time. An overall impression of a product is derived from the reflective level, as with a re-evaluation of past experience. Therefore, the volume of positive emotion is drawn by re-evaluating past experience at the reflective level and an obtained positive emotion, such as joy, through a surprise during a use-experience of a product at the behavioural level. We considered that Kando is generated when the volume of positive emotion is significant. Thus, whether a subject’s Kando type is Responsive (easily moved) or Resistive (difficult to move) this can be determined by a disciplined examination of the subject’s re-evaluation process.

Furthermore, the AIDEES model\(^10\) is such that, “Consumers use care with things, attend to them, desire, experience their brand, become enthusiastic through their experience, and consumer’s impression, especially Kando, is told to other consumers and shared.” When sharing, information about products is provided via WOM communication. Thus, an attractive product is something about which customers expressed Kando through consumer-related behaviour.

Therefore, the authors’ propose that “Kando is generated by the interaction of the behavioural level and the reflective level, when a favourable experience, including a surprise, is greater than a past experience during the re-evaluation process”\(^7,8\).

To gather Kando requirements by focusing on WOM communication, ICSS includes World Café methodology\(^11\) through consideration of the AIDEES model, because World Café methodology can generate pseudo WOM. An outline of the Kando Understanding Support Process within ICSS is shown in Fig. 1.

World Café in the Kando Understanding Support Process was organized within the following parameters. The theme of the discussion was “What are things eliciting Kando?” In Round 1, participants record those things eliciting Kando—especially elements at the reflective level; an opportunity to handle things, an impression, and an expectation—on a sheet of paper. In Round 2, participants write down Kando requirements—a thought when they experienced Kando, a past story of personal experience, an environment—at the behavioural level via the user-centered design. Additionally, the Kando requirements are grouped according to the classification table of Kando words\(^12\) as shown in Table 1. In Round 3, participants write down requirements which connect Round 1’s things with Round 2’s requirements (See Fig. 2). In the final session, participants write down important impressions and words from the Kando words table (See Table 1) on sticky notes. All sticky notes are attached to the Final Sheet with the Future-Past and the Share-Individual axis (See Fig. 3). Moreover, Table 2 shows the Kando requirements drawn from the groups, through clustering the elements in the Final Sheet, according to Kando words. During these rounds, we are able to obtain Kando requirements using these sheets. Kando requirements and customer needs so obtained are set into the Requirement-Solution’s Quality Function Deployment (QFD) matrix as part of the analysis results for the problem understanding process of the Creative and inventive Design Support System (CDSS)\(^13\). The defined problem, i.e., requirements, can be solved using the translated design solutions via ideas obtained during the CDSS problem solving process, especially contradiction solving (Phase 2), using TRIZ methodology.

(a) 1st of four working Café tables

(b) 2nd of four working café tables

Fig. 1. Outline of ICSS\(^7,8\)

Fig. 2. Examples of World Café round 3 sheets
This study’s objective is to develop an assessment system using ICSS, including quality assurance, for creating ideas for attractive products. Because the ICSS Kando Understanding Support Process depends heavily on the human mind and emotion, quality assurance for ICSS is certainly needed. A V-model with Verification & Validation (V&V) was introduced to the assessment system, and the authors began to verify the Kando Understanding Support Process for ICSS using the verification process of the proposed assessment system.

In this paper, we propose a validation process for the ICSS idea creation process—from gathering Kando requirements, to creation of the idea. This proposed validation process was carried out using TM and fNIRS bioinstrumentation. As the result of the validation, we confirmed that this process is desirable for developing an idea, and also confirmed the positive expectation for an idea in terms of Kando requirements through the activation of the left side prefrontal area of the brain.

2. V&V process in the assessment system

In our study, an assessment system for ICSS quality assurance was developed by applying a V-model. The V-model is used to visualize definition/decomposition/V&V of the system engineering activities during the project life cycle process, especially the concept and development processes. The quality assurance system for ICSS based on a V-model is shown in Fig. 4. In Fig. 4, the left-hand process branch of the “V” is the Kando Understanding Support Process, providing for the definition of Kando requirements on a QFD matrix for CDSS through gathering, analyzing, classifying (by Kando words), and the selecting of Kando requirements via World Café methodology. To satisfy these defined requirements, ideas are generated at the bottom step. From the lower right step of the “V”, the verification of obtained Kando requirements, and the validation as to whether the generated ideas are appropriate for action. The assessment system defined according to the V&V methodology of the V-model is as follows:

- Verification of a Kando requirement: “Has the Kando requirement been chosen correctly?”
- Validation of a Kando requirement: “Has the idea properly embodied the Kando requirement?”

The V&V on V-model is described in the next sections.

---

**Table 2. Kando requirements obtained from the Final Session**

<table>
<thead>
<tr>
<th>No.</th>
<th>Kando word</th>
<th>Kando requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Delight</td>
<td>Experience of an infrequent things</td>
</tr>
<tr>
<td>2</td>
<td>Abundance</td>
<td>Feel-good</td>
</tr>
<tr>
<td>3</td>
<td>Awakening</td>
<td>Apply traditional technologies</td>
</tr>
<tr>
<td>4</td>
<td>Excitement</td>
<td>A liking differs</td>
</tr>
<tr>
<td>5</td>
<td>Abundance</td>
<td>Hospitality such as the theme park</td>
</tr>
<tr>
<td>6</td>
<td>Excitement</td>
<td>Use accessible things for a long time</td>
</tr>
<tr>
<td>7</td>
<td>Relish</td>
<td>Surprise of the first time we came up to Tokyo</td>
</tr>
<tr>
<td>8</td>
<td>Relish</td>
<td>Visit to the home town</td>
</tr>
<tr>
<td>9</td>
<td>Fascination</td>
<td>Surprise of the first time snow was seen</td>
</tr>
</tbody>
</table>

---

**Table 1. Classification of 150 Kando words**

<table>
<thead>
<tr>
<th>Major Class</th>
<th>Middle Class</th>
<th>Representative words</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundance</td>
<td>Fill one’s heart, Love, Good, Tears</td>
<td></td>
</tr>
<tr>
<td>Relish</td>
<td>Heart-warming, Thank you, Serenity</td>
<td></td>
</tr>
<tr>
<td>Fascination</td>
<td>Be fascinated, Beautiful, Majestic, Silent as spite of oneself</td>
<td></td>
</tr>
<tr>
<td>Excitement</td>
<td>Touch a person’s heart, Heart becomes hot</td>
<td></td>
</tr>
<tr>
<td>Delight</td>
<td>One’s heart jump, Tasty, Sympathy, Hot dog!, Fulfillment</td>
<td></td>
</tr>
<tr>
<td>Grief</td>
<td>Feel shivers down one’s spine, Panic, Surprise, Tension</td>
<td></td>
</tr>
<tr>
<td>Awakening</td>
<td>Clutch one’s heart, heart is beating, Tremulous, Get goosebumps</td>
<td></td>
</tr>
</tbody>
</table>

---

**Fig. 3. Example of World Café final sheet**

**Fig. 4. The assessment system of the Kando Understanding Support Process based on a V-model with V&V**

2.1. The verification process of a Kando requirement

In order to verify whether Kando requirements are selected correctly, Design Of Experiment (DOE) is used in the Kando requirement verification process. This DOE’s design factors (control factors) employ the major class labels of Kando words and the axes of the Final Sheet in the World Café process. As for Kando requirements extracted based on the combination of these design factors, by means...
of a five-grade evaluation using the Likert scale, and DOE, we wanted to know whether we could validate test subjects’ answers to this question: “Does this inspire Kando in you?” Moreover, the desirable Kando requirement is verified through an evaluation of both an emotional effect and a positive expectation (prediction)—the activation of the left side prefrontal area in the brain—by the hybrid verification method of combined SD and fNIRS. The details and results of this verification process were described in Ref. 15.

2.2. The validation process of Kando requirements

For the validation of Kando requirements, we are presented with a Hybrid method including TM and fNIRS. TM took noise factors into account. Two noise factors were defined by two level factors, i.e., gender and the level of ease for Kando expression. Moreover, TM was assigned three design factors. 1: the Kando word; 2: time axis; and 3: human axis. In turn, these three factors each used three defined levels. The Kando word levels were: 0: Expressivity (Negative emotions), 1: Receptivity, 2: Expressivity (Positive emotions). The time axis levels were: 0: Current, 1: Past, 2: Future. And the human axis levels were: 0: Neutral, 1: Individual, 2: Share. Therefore, an orthogonal array L9 (34) with noise factors was used. By using this TM, we consider that a robust Kando Understanding Support Process can be validated to the variation in noise factors, such as a subject’s level of ease for Kando expression. Moreover, this validation process’s result is evaluated by examining “Does this inspire Kando in you?” (See Fig. 5) by a Semantic Differential scale for SD analysis. Additionally, for the validation of a created idea, we check the activation of the left side prefrontal area of the brain as to a positive expectation, since the oxy-Hb exceeded the deoxy-Hb into the task phase of the experiment as measured by fNIRS. Kando is expressed by positive emotion due to the activation of the left side prefrontal area of the brain

Consisted of 20 subjects (11 male and 9 female). The sheets from Round 3 and the Final Sheet of this World Café are shown in Fig. 2 and Fig. 3, respectively. From the results of this World Café, Kando requirements (see Table 2) were drawn from the Final Sheet.

For the creation of an attractive new vacuum cleaner, the ICSS QFD matrix consisted of selected Kando requirements; requirements from the needs for a vacuum cleaner; and initial ideas, as shown in Fig. 6. If an idea for a requirement is a solution, “O” is used, whereas, if there is a conflict, “X” is placed in the QFD matrix. For example, it’s apparent that two requirements—“Controlling by brain-wave” and “Coupling to applications”—are conflicting initial ideas.

3. Idea creation using ICSS for an attractive new vacuum cleaner

The World Café process for Kando understanding was carried out using student participants. The participants

Fig. 5. The evaluation deployment tree of validation criteria

Fig. 6. ICSS QFD matrix for a vacuum cleaner

To solve a contradictory relationship, ICSS includes a contradiction matrix of TRIZ methodologies. Improving and worsening features—i.e., “Extent of automation” and “Device complexity”—of this example’s contradiction (see Fig. 7) were deployed, and “Vacuum cleaner with BMI (Brain Machine Interface)” was created as a new idea by applying Principle 24, “Intermediary,” of the inventive principles of TRIZ.

This created new idea is then validated by using the proposed validation of the Kando understanding process with an assessment system based on a V-model with V&V.

Fig. 7. Idea creation using contradiction resolution from TRIZ

Assessment system

Contradiction solving

ICSS Matrix

QFD

Principles

Vacuum cleaner

Created Idea

Controlling by brain-wave

16 Extent of automation

Coupling to applications

16 Device complexity

Vacuum cleaner

With BMI

(Brain Machine Interface)
4. Validation of a created idea through SD and fNIRS

This created new idea was assessed through the SD method using 9 students (8 male and 1 female) as subjects. This assessment evaluated “Does this inspire Kando in you?” based on criteria shown in Fig. 5. Moreover, the subjects’ cerebral blood flows, when visualizing exposure to this new idea in their minds, were measured using fNIRS.

First, to control for the effects of ease of Kando expression, the subjects were classified into two types, Responsive and Resistive, by using the SD method. As for the Kando requirements defined as requirements in the QFD matrix, the question, “When you underwent this experience, how did you feel?” was asked and the responses evaluated. The evaluation criteria for the SD method included six items which consisted of three items each of evaluation criteria for validation as in Fig. 5, and three items picked up from the classifications of Kando words (See Table 1), respectively. The average for questionnaire results for the SD method is shown in Fig. 8. Through classification of the SD analysis results, we obtained an average for subjects responsive to expressing Kando (left line), and an average for subjects resistive to expressing Kando (right line), and the subjects’ combined average (central line) in Fig. 8.

Next, in order to validate the results of the SD method, they were compared with the fNIRS measurement data. From these results, including fNIRS consideration, we confirmed that although subjects’ response types differ, results from the SD method pointed to Responsive types for Kando expressiveness. Moreover, the average for cerebral blood flow measurement data for Kando expression influenced assessment estimation. Therefore, a Kando requirement selection process with little control over the ease Kando expression during a World Café exercise is validated as to type of process by using TM. For this validation, the orthogonal array L9(3^4) which used ease of Kando expression as a noise factor, is shown in Table 3.

5. Validation of created ideas through TM

The experimental result of fNIRS showed that ease of Kando expression influenced assessment estimation. Therefore, a Kando requirement selection process with little control over the ease Kando expression during a World Café exercise is validated as to type of process by using TM. This assessment evaluated “Expressivity (Positive emotions) × Future” had a high value factor combination regardless of Responsive or Resistive type of Kando expression. However, the human axis’ level showed a different result, i.e., Responsive and Resistive types of Kando expression came out as “Share” and “Individual” respectively.
6. Conclusion

From the discussion above, the validation process of the assessment system for a Kando Understanding Support Process was performed by using the V-model with V&V. As a result, we confirmed the following:
- The validation process is a desirable process for carrying out an assessment of TM combined with the SD method and fNIRS.
- Responsive types for Kando expression hold positive expectations for new idea.
- Factors which Ease of Kando Expression influences greatly are “share” and “individual”, along the human axis.
- The validation process of ICSS from the Kando Understanding Support Process to idea creation is greatly influenced by Ease of Kando Expression.

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References

Papers presented at previous ETRIA conferences and other publications
Establishing General Methodology of Creative Problem Solving & Task Achieving (CrePS): Organizing Different Methods and Their Application Cases with the Six-Box Scheme

Toru Nakagawa¹,²,³,⁴,*

¹ Osaka Gakuan University, Emeritus Professor, 2-36-1 Kishibe-Minami, Suita, Osaka 564-8511, Japan
² CrePS Institute, 3-1-13 Eirakudai, Kashiwa, Chiba 277-0086, Japan *

* Corresponding author. Tel.: +81-4-7167-7403; fax: +81-4-7167-7403. E-mail address: nakagawa@ogu.ac.jp

Abstract

'Creativity methods' or 'Problem solving methods' have been much studied, but have not been spread widely enough so far. It is mostly because such methods have been partial and not organized well due to the lack of general frameworks. Thus the present author have been proposing since 2012 to establish 'General Methodology of Creative Problem Solving & Task Achieving' (abbreviated as 'CrePS') and spread it widely. In the present paper I am clarifying the vision of the CrePS methodology and am reporting the progress in the research for establishing it. As the framework of the CrePS methodology we adopt a new paradigm of creative problem solving, i.e. 'Six-Box Scheme'. This scheme clarifies the different roles of the 'Real World' and the 'Thinking World'. The Six-Box Scheme, on the contrary to the conventionally used 'Four-Box Scheme' of abstraction in science and technology, has clear and detailed guidelines of what information is to be obtained/clarified in each box, or the stage of problem solving.

I am currently working to interpret various case studies of creative problem solving in terms of the Six-Box Scheme to build a collection of case studies of applying the CrePS methodology. I am also working to describe what kind of information is desired at each stage (or box) of CrePS and how to obtain it, in a hierarchical manner. Such description is expected to make a common platform to discuss about the methodologies of creative problem solving on academic and objective bases. I wish you to share the vision and to collaborate in the study.

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Keywords: Creative problem solving; General methodology; Six-Box Scheme; CrePS; Case studies; Cooperative work

1. Introduction

Solving problems (i.e., the undesirables) creatively and achieving tasks (i.e., the desirables) creatively have been tried, practiced, and carried out successfully by humans in all the areas (e.g., society, business, technology, science, etc.) and in all the eras and regions in order to construct the human culture. Therefore in everything around us and in everything of society and technology etc., a variety of results of creative problem solving by many people in different eras are embedded.

However various trials for achieving the results and various methods of creative problem solving and task achieving have rarely been recognized well nor recorded explicitly. The processes of achieving the results are quite different from one another depending on the problems and situations, and hence the methods/techniques which have been abstracted from various cases do differ much and are often partial and inconsistent.

Hundreds of methods of creative problem solving (or roughly so called 'creativity methods') have been known so far [1]. Such methods pursue different types of approaches which put stresses on different aspects, such as:

- Use of knowledge in science and technology (from principles to patents)
- Learning from previous cases/examples
- Recognizing and analyzing the problem/task
- Assisting the idea generation
- Mental aspects
- Concretizing and realizing the ideas
- Forecasting the future and predicting the directions
- Methodological structure

All these aspects are of course useful and important. But the people who emphasize some of these aspects or promote some individual techniques often disagree and fight with one another. It is because the conventional methods and schools of thoughts are diverging and inconsistent lacking a structure to organize them and lacking an appropriate methodology for unifying them, I think.

The present author has been working to do research and to proliferate TRIZ (i.e., Theory of Inventive Problem Solving) [2] and USIT (i.e., Unified Structured Inventive Thinking) [3] since 1997. In 2012, however, after reflection of the difficulty in the proliferation of these methods in spite of much general needs by society, I realized it necessary and appropriate to establish a more general methodology at a level...
higher than these individual methods and to spread it widely. Thus I proposed a new target as follows [4]:

“To establish ‘General Methodology of Creative Problem Solving and Task Achieving’ (abbreviated as CrePS), To spread it widely, and To apply it to the jobs of problem solving and task achieving in various areas in the country (and in the world).”

Further in 2013, I showed the vision of this new methodology, named as ‘CrePS’ in abbreviation [5]. And I showed that the ‘Six-Box Scheme’ derived from USIT should be useful as the framework of the CrePS methodology and that the contents of CrePS can be clarified effectively through the studies of TRIZ/USIT at first.

The present paper clarifies further the intention of CrePS and reports the current status of studies for establishing CrePS.

2. Paradigm Shift: Four-Box Scheme => Six-Box Scheme

As the framework/paradigm of creative problem solving, conventionally science and technology have been using so far the ‘Four-Box Scheme of abstraction’ (Fig. 1).

![Fig. 1. Four-Box Scheme (conventionally used in science and technology)](image)

For solving difficult problems, it is advised to raise the problem at a higher or generalized level of abstraction, instead of trying to solve it at the concrete level. Then the knowledge and method in science and technology would help to give a solution at the generalized level. Thus the problem solver should try to concretize the general solution into a specific one. Based on this paradigm, a huge number of systems of theories, models, and knowledge bases have been built and accumulated in all the areas of science and technology.

The Four-Box Scheme works effectively in various established fields. However, the scheme faces difficulty for the problems without known previous cases, across a number of different fields, and hence requiring real creativity for solving them. To such cases, TRIZ has contributed much by building multiple sets of models, techniques, and knowledge bases, which are useful across fields (of mostly technology) [2].

However, the usage of each model in the multiple sets is carried out by fitting the problem to the preset categories in the model, resulting in partial and insufficient analysis of the problem. Thus the generalized solutions obtainable from the model are given just as hints/suggestions. The user has to find some ideas for his own system by some analogical thinking from the hints.

The Four-Box Scheme has also a fundamental pitfall that the contents of generalized problems and generalized solutions depend individually on the models and hence that their contents cannot be explained any further in general terms across the models. This fact denies to give any useful instructions how to think for analyzing the problem, generating solution ideas, and concretizing them in an abstract level.

The present author proposed the ‘Six-Box Scheme’ as a ‘New Paradigm of Creative Problem Solving’ [6]. The scheme is illustrated in Fig. 2, and its features are as follows:

![Fig. 2. Six-Box Scheme of CrePS](image)

(a) The scheme is carried out in two different worlds, i.e., the ‘Real World’ and the ‘Thinking World’, which have their own roles respectively. The Real World is the concrete world where various activities of society, business, technology, etc. are carried out under their own value criteria and constraints. The Thinking World, on the other hand, is the world where problems can be considered with the guidance of problem solving methodology and temporarily free from various constraints, and it is requested to propose possible solution concepts.

(b) The ‘problem situations’ (in Box 1) need to be recognized and addressed by the activities (e.g., business activities) in the Real World. A problem need to be recognized and the situations around the problem should be understood.

(c) ‘Problem and task to be addressed’ (in Box 2) should be defined on the basis of concrete data and the priority criteria in the Real World, and is handed to the Thinking World asking for their consideration and solutions. The Thinking World must understand the request from the Real World by confirming and enhancing the information in Box 2.

(d) In the Thinking World, the problem is analyzed first to obtain the information in Box 3. First, the present system must be understood. For this purpose, the present system is analyzed in terms of space and time characteristics, and components (or objects), attributes (or properties), and functions, to obtain the understanding of the mechanism of the system and of the (root) causes of the problem.

Second, the ideal system must be understood also at this stage. We should understand what the desirable behaviors and desirable properties are of the ideal system and what the ideal
result/goal is, even though we do not know how to reach the goal yet.

It is very important at the stage of Box 3 to understand both the present and ideal systems. For deriving such information, standard analysis methods in the CrePS methodology can give good guidance but concrete/technical understanding of the system is also necessary.

(e) Information in Box 4 is ‘Ideas for a new system’, which is ahead of the suggestions/hints of generalized solutions in the conventional Four-Box Scheme. Various techniques for stimulating/generating such ideas have been known and can be used for obtaining the information of Box 4. However, in the CrePS process, once we understand the present system and ideal system at the previous stage (Box-3), our brains usually work actively to generate ideas in Box 4 in a natural, spontaneous, and smooth manner.

(f) Box 5 contains the information of ‘Solution concepts’ which are to be constructed on the basis of the ideas of Box 4. They should be proposals of solutions that are expected to work properly and to solve the problem, to the best of the problem solving team (or person). For constructing such a solution, (technical) capability in the relevant areas is necessary rather more than the skills of problem solving.

(g) Then the Real World should receive the conceptual solutions from the Thinking World and evaluate them and finally implement them into actual concrete solutions (in the products/manufacturing processes/services, etc.).

3. Framework of the CrePS Methodology

At ETRIA TFC last year, I showed the vision of the CrePS methodology and described in some detail about the requirements of information to be prepared for each of the six boxes. At that time I was definitely convinced of the following three points.

- The CrePS methodology is definitely possible to be constructed by use of the Six-Box Scheme as the paradigm (as discussed in the previous section).
- The contents of the CrePS methodology can be supplied sufficiently by various known methods including TRIZ.
- Concise and consistent processes are necessary for performing the CrePS methodology for various purposes.

USIT provides a good example of such a concise and consistent CrePS process for a general use.

I am now working to construct the CrePS methodology in these prospects.

A figure which I recently drew has given me a new and clear suggestion. See Figure 3.

Fig. 3. Six-Box Scheme and the Real World

This figure represents the relationships between the Real World and the Thinking World in the Six-Box Scheme (better than Fig. 2). In the big streams of activities (e.g., industrial activities) in the Real World, different problems are required to be solved at different stages, and hence the jobs of ‘Creative Problem Solving’ (i.e., CrePS) need to be carried out many times. Such activities for problem solving are carried out sometimes by special projects, by small teams, and some other times by individuals, where the Thinking World is formed conceptually.

It is remarkable that even though the Six-Box Scheme was newly proposed explicitly, it is quite natural and probably well-known implicitly, I believe. It represents the usual ways of successful problem solving done by many people in the world of science and technology.

Representation of many examples of activities for research, development, discussion, etc. would vividly show the cases of success and cases of failure as well.

4. Current State of Constructing the CrePS Methodology

In order to pursue the vision of CrePS proposed last year [5], I am currently working in the following 4 aspects.

(1) To make a collection of case studied of CrePS application by using problem solving examples already published.

(2) To understand various methods/techniques in addition to TRIZ and to introduce and organize them in CrePS.

(3) To relate CrePS with various activities of the Real World.

(4) To categorize various requests/purposes of applying CrePS and to propose concise and consistent processes of applying CrePS for each purpose.

The present paper reports the current, intermediate progress of (1) and (2). I am also working to study on (3) and (4) along the suggestions represented in Fig. 3, but will not be described in the present paper.

5. Making a Collection of CrePS Application Case Studies

CrePS application case study means a study example of applying a creative problem solving method to solve a
problem. Thus such case studies can be effectively obtained by re-describing known good problem solving cases in the new framework and terms of CrePS, rather than by trying to make new cases of application.

It should be noticed that the cases for study should be evaluated not mainly by the excellence of the results but rather by the fact that the process of problem solving is described well ready to understand and that many people can understand and follow the thinking process as a reference for their own problem solving. Most cases published so far are apt to describe only the process which led remarkable/brilliant results. The more brilliant the results and the processes are, the bigger jumps there often exist in (their descriptions of) the trial and thinking process, and hence the more difficult they are for novices to follow.

In this sense, case studies should be revised for educational purposes so as to describe various remarks/considerations in accordance with the CrePS methodology.

Thus at moment I am working to revise the TRIZ/USIT case studies I published so far where I solved familiar problems together with my students. Further on the basis of the recognition that USIT is a concise and consistent process of applying CrePS, I am currently describing the cases in the range of the USIT procedure.

Limitation in the number of pages of the present paper, such detailed description cannot be shown here. Instead I will show two cases of solving familiar problems in the six-box diagram in a simplified manner, assuming that the cases are already explained elsewhere.

Figure 4 is a summary of the case study of ‘How to fix the string found shorter than the needle’ [3].

Please see Box 4. One of the ideas for a new system is: “Since the experts’ technique handles the string in air at the positions just as the ideal system specifies, we should just assist the string to be placed at such positions in air”. The arrangement of the support is shown in the figure with x marks (i.e., the symbols of (magical) particles of the USIT method). Another idea was obtained with a trigger of a ridiculous idea of ‘Let’s break the needle now!’! By considering the implication of the ridiculous idea, we have found an idea “Since we have finished sewing now, we do not need the needle point any longer; we just need a short needle specialized for making a standard knot (or gem knot).” This is a good example for understanding what the key ideas are for a new system among the information along the process from problem analysis, to idea generation, and to solution construction.

The case of Water-saving toilet problem [7] is illustrated in Fig. 5, in a similar form of Six-Box representation.

The understanding of the present system shown in Box 3 (a) should be noticed. We understand that the reason for the toilet to need a much amount of water is the barrier of the S-shape pipe and that even though the S-shape pipe is useful for blocking the bad odor from the beneath it is harmful and should be removed when we flush the water. This is the recognition of a case of Physical Contradiction in TRIZ.

Next we obtain the understanding of the ideal system (in Box 3(b)) where the S-shape pipe must exist during ordinary time period while it must not exist during the water is flashed. This understanding corresponds to the contradiction separation in time in TRIZ.

Then in Box 4 we obtain the idea for a new solution system, saying: “Since the S-shape pipe means the pipe whose middle part is lifted higher than the entrance, we should just make the pipe flexible and lift its middle part in the ordinary periods and lower the part when we flush the water”. This case study clearly shows the process for solving Physical Contradictions, i.e., a core technique of TRIZ, in the Six-Box Scheme. The process is to recognize a Physical Contradiction in Box 3(a), to understand the ideal system with the separation principle in Box 3(b), and to generate ideas for a new system where the contradiction is solved in Box 4.

6. Organizing Various Problem Solving Methods in the CrePS Scheme

There are hundreds (or probably even thousands) of methods are known for creativity methods/creative problem solving in the world. Thus even if we show their names in a classified way, we cannot understand any essence of them. We rather want to refer such different methods in order to clarify the necessary information in every box of the Six-Box
Scheme. In each box of the Six-Box Scheme (or in each stage of creative problem solving), what kind of concepts, viewpoints, scope, and representation of information should we have? And how can we obtain such information/understanding?

For this purpose, I have specified the scheme and format of describing the information of each Box in a hierarchical/detailed manner in accordance to the CrePS vision. I have started the description of TRIZ/USIT methods in this scheme and am going to write down various principal methods (and their component methods) step by step. The system of CrePS documents is openly posted in the "TRIZ Home Page in Japan", for the purpose of public review and cooperative revision [8].

If we could accumulate the descriptions of different methods in such a clear framework/format of CrePS by a (large) number of researchers, they could form a basic platform for discussing about creative problem solving methodologies in an objective/academic manner.

In parallel to such work of detailed description, we need to visualize the positions of different methods (and their component tools) in the CrePS methodology.

The current tentative format is demonstrated below by using two examples, i.e., USIT [3] (Fig. 6) and Larry Ball’s Hierarchical TRIZ Algorithms [9] (Fig. 7). The outline and references are first written and then the features and evaluations are briefly described.

**Method: USIT (Unified Structured Inventive Thinking)**

Ref: Ed Schmitth "USIT" (1997); Toru Nakagawa, in "TRIZ Home Page in Japan" (1999-2014)

**Outline:** Started with a trigger of TRIZ and SAT, established as a compact and consistent full process for problem solving. Has the features of balancing the problem. Analyzing the present system in terms of functions and attributes, making images of ideal system, and future generations. Later in Japan, A system of operations for idea generation and the paradigm of Six-Box Scheme were devised. Currently regarded as a simple and consistent process for practicing the CrePS methodology.

**Features:**
- Clarify the purpose and ideas
- Clarify the needs and requirements
- Clarify the problem
- Clarify the system from the viewpoints of functionality

**Process:**
- Generate ideas for solutions
- Construct solution concepts
- Evaluate and select solutions
- Implement solutions

**Overall bases**
- Encourage active and flexible thinking
- Encourage system thinking
- System and consistency of the methodology
- Links with the activities in the Real World
- Assistant with software tools

**Method: Hierarchical TRIZ Algorithm**

Ref: Larry Ball, posted in "TRIZ Journal" (2005-2006)

**Outline:** A full process for creative problem solving, consisting of the steps: Discovery of market, Ideation functions, Clarifying the causes of the problem, Recognizing physical contradictions, Solving contradictions by use of separation principles, and Implementing solutions. Containing and recognizing all the TRIZ methods into this full process. The process of solving physical contradictions is particularly deep and rich.

**Features:**
- Clarify the purpose and ideas
- Clarify the needs and requirements
- Clarify the problem
- Clarify the system from the viewpoints of functionality

**Process:**
- Generate ideas for solutions
- Construct solution concepts
- Evaluate and select solutions
- Implement solutions

**Overall bases**
- Encourage active and flexible thinking
- Encourage system thinking
- Understand and utilize principles in science and technology
- Utilize concrete knowledge in science and technology
- Links with the activities in the Real World

Fig. 7. Description in the CrePS methodology: Larry Ball's Hierarchical TRIZ Algorithm

The first half of the features characterizes which process stages the method addresses and what kind of information it tries to clarify/obtain. The latter half, on the other hand, characterizes what types of thinking support the method uses, regardless the specific process stages. This gives some viewpoints for grouping the methods.

Selection of these viewpoints of features is important for building a system of the CrePS methodology. Each method is evaluated in these viewpoints roughly with five grades (0, 1, 2, 3, 4), and the evaluation is expressed in simple bar graphs. It is inevitable that the evaluation of each method in various viewpoints depends on the evaluator’s understanding of the specific method and of the general state-of-arts of the whole area of problem solving methods. Thus the evaluation may be qualitative, rough, and not fully objective.

By the way, a typical method of representing these relative characteristics may be the radar chart, having radiative axes. However, in the present paper I use bar graphs for clearly showing the evaluation in each viewpoint and for easier comparison among (many) methods in some specific viewpoints.

7. Concluding Remarks

As is described above, my work of constructing the CrePS methodology has been progressing rather slowly for a year since last conference. It is partly because I have been working hard for publishing the "TRIZ Practices and Benefits" book series (Vols. 1A, 2A, 3, 3S, and 4) from CrePS Institute [10] and for editing and improving the entrance pages (for children, for students, for engineer beginners, and for practitioners) of the public Web site "TRIZ Home Page in Japan" [11]. These activities are expected to strengthen the basis of proliferation of the CrePS methodology.

As I write in the present paper, the big vision of establishing the ‘General Methodology of Creative Problem Solving and Task Achieving (CrePS)’ is surely achievable step by step. I believe, even though probably taking a few decades for its wide spreading. Achieving the vision will make Creative problem solving being applied everywhere in the society in the world.
I heartily wish you, many researchers and practitioners, to share the vision and cooperate together.

References

[4] Nakagawa T. Multiple modeling to set up the problems/tasks: establishing and penetrating the methodology of creative problem-solving/task-achieving, 8th Japan TRIZ Symposium, Sept. 6-8 2012, Tokyo; posted in TRIZ Home Page in Japan, 2012
Abstract

The paper conceptualizes the systemic approach for enhancing innovative and competitive capacity of industrial companies (named as Advanced Innovation Design Approach – AIDA) including analysis, optimizations and further development of the innovation process and promoting the innovation climate in industrial companies. The innovation process is understood as a holistic stage-gate system comprising following typical phases with feedback loops and simultaneous auxiliary or follow-up processes: uncovering of solution-neutral customer needs, technology and market trends, identification of the needs and problems with high market potential and formulation of the innovation tasks and strategy, idea generation and problem solving, evaluation and enhancement of solution ideas, creation of innovation concepts based on solution ideas, evaluation of the innovation concepts as well as implementation, validation and market launch of chosen innovation concepts. The article presents the current state of innovation research and discusses the actual status of innovation process in the industrial environment. It defines the future research tasks for amplification of the innovation process with self-configuration, self-optimization, self-diagnostics and intelligent information processing and communication.

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Keywords: Innovation process; innovation strategy formulation; new product development; TRIZ methodology

1. Einführung und Motivation

Die Industrieunternehmen müssen den stets wachsenden internationalen Markt- und Kostendruck standhalten. Die Erschließung neuer Kundengruppen, Festigung der Kundenbeziehungen, die Schnelligkeit, neue Produkte oder Dienstleistungen auf den Markt zu bringen, sowie das Innovationskönnen der Mitarbeiter stellen für Unternehmen die zentralen Erfolgsfaktoren dar.

Trotz existierender firmeninterner Prozessabläufe, Richtlinien und Innovationsmethoden verlassen sich die vor allem kleinen und mittelständischen Unternehmen oft auf eigene Kreativität, Tradition und Intuition. Als Folge werden die erhofften Projektziele häufig nicht erreicht, Alternativen und Markchancen übersehen sowie Innovationsrisiken falsch abgeschätzt.

Um die Wettbewerbsfähigkeit der Unternehmen zu erhöhen und die Innovationsrisiken zu minimieren, gehört ein strukturierter Innovationsprozess schon heute zum unverzichtbaren Erfolgsfaktor in der deutschen Industrie. Ein derartiger Innovationsprozess ist aber bei vielen Unternehmen noch unvollständig definiert. Oft fehlt es in der Industriepraxis an einem abteilungsübergreifenden Innovationsmanagement oder an einer systematischen und vollständigen Erhebung der Kundenbedürfnisse als Quelle der Innovation. Der Innovationsprozess wird oft als Teil des
Stand der modernen Generation (um 1960): technische Generation (um 1980): interaktiver Prozess (interaction between research and market)

Trotz analoger branchenübergreifender Herausforderungen versuchen die Unternehmen oft Ihre Implementierung des Innovationsprozesses im Alleingang zu verwirklichen, ohne die existierenden Erfahrungen aus der Praxis und der Forschung umfassend zu berücksichtigen.

2. Zielsetzung

Dieser Beitrag beschreibt das Konzept einer universalen Vorgehensweise, definiert als Advanced Innovation Design Approach (AIDA), für die Industrieunternehmen, welche die Innovation als steuerbaren und auf hohem Qualitätsniveau reproduzierbaren Prozess organisieren sollte. Dafür soll eine Reihe von erforderlichen Maßnahmen auf den unterschiedlichen Unternehmensebenen, wie die Mitarbeiterebene (Qualifizierung), die Abteilungsebene (neue Methoden und Tools) oder die Unternehmensebene (Prozessabläufe, Vernetzung), identifiziert, entwickelt und verifiziert werden. Diese systemischen Maßnahmen sollen neue Impulse für die Steigerung der Innovationskraft geben und dadurch den Markterfolg und die internationale Wettbewerbsfähigkeit der Unternehmen sichern.

Der zu entwickelnde AIDA-Innovationsansatz soll folgende neue Erkenntnisse erbringen:
• Auflistung und quantitative Priorisierung des detaillierten Handlungsbedarfs inkl. zukünftiger Herausforderungen, um die Innovationskraft und die Wettbewerbsfähigkeit der Unternehmen zu steigern. Methodisches Vorgehen: Erfassung notwendiger Innovationsprozessschritte, Techniken und Maßnahmen; Bewertung deren Wichtigkeit und des aktuellen Erfüllungsgrades im Rahmen von qualitativen und quantitativen Analysen.
• In Bezug auf das Konzept der vierten industriellen Revolution Industrie 4.0 sollen vor allem die Verfahren der Computer-Aided-Innovation (CAI) und der modernen Prozessüberwachung zur Selbstoptimierung, Selbstkonfiguration, Selbstdiagnose und Informationsverarbeitung im Innovationsprozess untersucht werden.
• Entwicklung eines universellen und anpassbaren Innovationsprozessablaufs und einer Reihe von Standardlösungen für unterschiedliche Innovationsaufgaben für die Produktentwicklung und Prozessoptimierung in der Industriespraxis.
• Steigerung der Innovationskompetenzen der Mitarbeiter und ihre bessere Vernetzung im Innovationsprozess.

3. Stand der Forschung

Der marktorientierte Innovationsprozess zählt seit langer Zeit zu den strategischen richtungsweisenden Prozessen der Industrieunternehmen, die materielle Güter entwickeln. Um ihn so effizient wie möglich zu gestalten und korrekte Entscheidungen zu treffen, werden die Innovationsmodelle, -konzepte und -methoden stets weiterentwickelt. Der Stand der Innovationsprozesse in verschiedenen Industriezweigen kann daher evolutionsbedingt sehr unterschiedlich sein, wobei alle sechs bekannten Generationen des Innovationsprozesses heute in der Industrie vertreten werden (Kotsemir und Meissner, 2013):
1. Generation (um 1960): technisch-orientierter Innovationsprozess (technology push),
2. Generation (um 1970): marktorientierter Innovationsprozess (market pull),
3. Generation (um 1980): interaktiver Prozess (interaction between research and market),
4. Generation (um 1990): integrierter Prozess (simultaneous process with feedback loops),
5. Generation (um 1992): Netzwerk-Innovationsprozess (Networking),

In Bezug auf die Koordination der Innovationsprojekte werden in (Lühring, 2006) 4 folgende Grundtypen von Innovationsprozess-Modellen definiert:
I. Funktional-arbeitsteiliges Modell - der Innovationsprozess richtet sich nach der Unternehmensstruktur;
II. Stage-Gate-Modell - der Innovationsprozess ist in verschiedenen aufeinanderfolgenden Phasen aufgeteilt (vgl. auch Cooper & Kleinschmidt, 2007);
III. Parallelisierungsmodell - Weiterentwicklung des Stage-Gate Modells durch die Überlappung einzelner Phasen;
IV. Modell der integrierten Produktentwicklung - Weiterentwicklung der Ansätze aus dem
Simultaneous Engineering, nach dem ein multifunktionales Team über die gesamte Projektdauer arbeitet und dabei die externen Erkenntnisse (Kunden, Lieferanten) und die internen Eingaben (Entwicklung, Produktion) kontinuierlich berücksichtigt.

Neu und eine Untersuchung wert wäre dabei eine Anwendung im Innovationsprozess der aus der agilen Softwareentwicklung bekannten Projektmanagement-Methode Scrum (s. Schwaber und Sutherland, 2013), die einem iterativen und integrierten Arbeitsprozess mit multifunktionalen Teams entspricht. Allerdings erfolgen der Innovationsprozess und insbesondere die Ideenfindung in meisten Softwareunternehmen größtenteils unsystematisch und sind oft dem Zufall überlassen.

Im Beitrag von Arenz (Arenz, 2003) wird angemahnt, dass die Innovationsprozesse der internen IT-Abteilungen von Industriewerken sich sehr oft im rudimentären Zustand befinden, wobei die Ausgangssituation und die Zielsetzung meist unklar definiert werden. Es fehlen in der Regel sowohl die geeigneten Prozessdefinitionen für IT als auch die entsprechende Softwareunterstützung, die den Innovationsprozess auf einem hohen Qualitätsniveau reproduzierbar macht.


Im Rahmen des Europäischen Programms ITEA2 (Information Technology for European Advancement) sind 8 grundlegende Bereiche mit insgesamt 46 Einzelaktivitäten für die Softwareinnovation erfasst worden (Pikkarainen et al., 2011). Die Teilnehmer des Projekts haben angenommen, dass es keinen gemeinsamen Innovationsprozess bei der Softwareentwicklung geben kann und haben sich daher mit den Einzelwerkzeugen und Methoden befasst. Ein Softwareunternehmen soll selbst entscheiden, welche Innovationsbereiche und Einzeltools für seine Aufgaben am besten geeignet wären.


Eine im Rahmen eines angewandten Forschungsprojekts mit verschiedenen Schweizer Firmen entwickelte Methode zum Innovationscontrolling unterstützt Unternehmen, ihr Innovationssystem in integraler Weise zu analysieren und zielorientiert zu verbessern (Bürgin, 2007). Die Fragen, ob die empfohlenen Maßnahmen tatsächlich zur Steigerung der Innovationsfähigkeit führen, und ob ein Unternehmen die komplexe Methode selbständig anwenden kann, bleiben allerdings offen.


Generell wird der früher dominierende ideenzentrierte Innovationsprozess, der mit der Phase der Invention (Schachtn, 2001) bzw. mit einer „starken“ Idee beginnt, in der letzten Dekade durch den kundenbedarf-orientierten Innovationsprozess ersetzt, in dem primär die lösungsneutralen „wahren“ Kundenbedürfnisse mit hohem Marktpotenzial als Basis für eine Innovationsstrategie im Vordergrund stehen (Ulwick, 2002), (Lichtenhalter et al., 2003), (Narver, 2004), (Livotov, 2005), (Du Preez et al., 2006); (Walther und Chevalier, 2009), (Pfund, 2013), (Konyha, 2014).

Wie in der Abbildung 1 schematisch dargestellt, besteht ein Stage-Gate-Innovationsprozess, eingeführt und konzipiert bei R.G. Cooper (Cooper, 2001), bei den erfolgreichen und innovativen Industrieunternehmen in seinem frühen Abschnitt aus der Strategischen Phase und der Umsetzungsphase (Livotov, 2005):

- **Strategische Phase:** Analyse der Ausgangssituation am Markt → Definition der Ziele → Erfassung der lösungsneutralen Kundenbedürfnisse → Priorisierung der Kundenbedürfnisse → Definition der Innovationslastenhefts bzw. der Innovationsstrategie.

- **Umsetzungsphase:** Systematische und kreative Ideengenerierung → Ideenbewertung → Erstellung von Innovationskonzepten aus den besten Ideen → Bewertung der Innovationskonzepten → Auswahl und Optimierung des besten Innovationskonzepts → Umsetzung des besten Konzepts.
Eine unzureichende Strategiedefinition, die schwach geprägten Feedbackloops und Interaktion zwischen den einzelnen Prozessphasen (dargestellt mit den Strichlinien in der Abbildung 1), sowie die Prozessunterbrechungen, wie z.B. bei der Überführung von Ideen in neue Produkte, sind aber charakteristische Schwachstellen in der Praxis.

Zum entscheidenden Erfolgsfaktor der Strategischen Phase gehört eine vollständige Erfassung bestehender und verborgener Kundenbedürfnisse. Dabei soll es aus einer Kundenanforderung oder Idee ein lösungsneutraler Kundenvorteil (Benefit) korrekt verstanden werden. In anderen Worten nicht der eigentliche Kundenwunsch zählt, sondern das, was den Kunden nachhaltig zufrieden macht. Zum Beispiel, wünscht ein Kunde einen leistungsfähigen Akku (technische Lösung) für ein Mobilgerät, so lautet offenbar sein lösungsneutraler Benefit „ohne Netzanschluss länger arbeiten“. Erfolgreich wachsende Unternehmen sollen genau wissen, was Ihre Kunden tatsächlich wollen. Der z.B. späte Apple’s Einstieg in den MP3-Markt war gelungen, weil das Unternehmen den ausschlaggebenden Kundenbenefit verstanden hat, eigene Musiksammlung sicher und einfach zu verwalten. Deshalb hat Apple nicht nur einen besseren MP3-Player entwickelt, sondern eine innovative IT-Lösung mit der iTunes-Software und dem iTunes-Store (Walther und Chevalier, 2009).

In der Regel beziehen sich die ausgesprochenen Kundenanforderungen für neue Produkte auf die bereits bekannten technischen Lösungen oder Technologien. Wenn ein Unternehmen die formulierten Kundenanforderungen oder -ideen direkt umsetzt, produziert es oft die sogenannten „me-too“-Produkte, die auch vom Wettbewerb angeboten werden. Durch solche Innovationen entstehen für Unternehmen keine nachhaltigen Wettbewerbsvorteile am Markt. Somit soll ein moderner Innovationsprozess in seiner frühen strategischen Phase die Arbeitsschritte für die vollständige Erfassung von lösungsneutralen und messbaren Kundenbenefits vorsehen, wenn auch für die noch keine zufriedenstellenden technischen Lösungen existieren.

Aus der Literatur werden für die Definition der markt- und kundenorientierten Innovationsstrategie bzw. des Innovationslastenhefts folgende Methoden bekannt:

2. Funktionsanalyse mit der Erfassung von nützlichen und unerwünschten Eigenschaften bestehender Produkte (Livotov, 2008),
3. Analyse des Arbeitsprozesses der Kunden - s.g. „job mapping“ (Bettencourt und Ulwick, 2008),
4. Analyse der gesellschaftlichen und technologischen Trends am Markt (Knope et al., 2011),

Im Zeitalter der elektronischen und IT-Revolution wird der zunehmende Bedarf der Kundenintegration in die Innovationsprozesse bei Hybridprodukten, die aus den Hardware- und Softwarekomponenten bestehen, immer wichtiger. Im Konferenzeintrag (Hoffmann et al., 2009) wird der weitere Forschungsbedarf für folgende Richtungen hervorgehoben:

- Eine systematische Erhebung und Bewertung von Methoden für die Kundenintegration,
- Untersuchung unterschiedlicher Formen von Kundeninputs als Bedürfnisse und Lösungen,
- Produktlebenszyklus übergreifende Integration des Kunden in den Innovationsprozess.


gibt sich nicht mit Kompromisslösungen zufrieden und richtet den Blick über den Tellerrand hinaus.


<table>
<thead>
<tr>
<th>Numerierung</th>
<th>Beschreibung</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tool für Moderation von Produktentwicklungs- und Problemlösungswerkshops mit der TRIZ Methode.</td>
</tr>
<tr>
<td>2</td>
<td>Strukturiertes Brainstorming 40x40: 40 Ideen mit 40 TRIZ Lösungsprinzipien schnell generieren.</td>
</tr>
<tr>
<td>3</td>
<td>TRIZ Inventor: Lösung von schwierigen technischen Problemen mit dem Erfindungsalgorithmus ARIZ.</td>
</tr>
<tr>
<td>4</td>
<td>Strategische Potenzialanalyse: Erfassung von Kundenanforderungen und Formulierung von Innovationslastenheften mit hohem Marktpotenzial.</td>
</tr>
<tr>
<td>5</td>
<td>Konzeptentwicklung: Umsetzung von definiten Innovationslastenheften (s. Tool 04) in die Innovationskonzepte.</td>
</tr>
<tr>
<td>6</td>
<td>Entwicklungstrends: Erfassung relevanter Entwicklungstrends und Vorhersage möglicher zukünftiger technischer Produktmerkmale.</td>
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<td>7</td>
<td>Ursache-Wirkung-Analyse: Ursache-Wirkung-Analyse zur Beseitigung schädlicher Wirkungen und unerwünschter Erscheinungen.</td>
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<td>9</td>
<td>Prozessinnovation: Prozessinnovation und Prozessoptimierung in der Verfahrenstechnik, Montage, Produktion, etc.</td>
</tr>
<tr>
<td>10</td>
<td>Antizipierende Fehlererkennung: Vorausschauende Erkennung von verdeckten Fehlern und technischen Risiken in neuen Produkten.</td>
</tr>
<tr>
<td>12</td>
<td>Patentoptimierung: Umgehung von Wettbewerbspatenten und Erhöhung des Innovationspotenzials eigener Patentanmeldungen.</td>
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</table>

Tabelle 1: Beispiel möglicher TRIZ-basierter Standardtools für den Innovationsprozess mit der AIDA-Unterstützung

Die wichtigsten Bestandteile und Tools der TRIZ-Methodik werden in der Tabelle 2 im Anhang zusammengefasst (Livotov, 2002).

4. Methodisches Vorgehen und Ausblick

Die Entwicklung des AIDA-Ansatzes befasst sich somit mit einer Fragestellung, die nach dem gegenwärtigen Forschungsstand noch nicht vollständig beantwortet ist. Für die Umsetzung des AIDA-Ansatzes wird ein zweistufiges Vorgehen geplant, welches sich in eine Forschungs- und Entwicklungssphase und eine Implementierungsphase gliedert.


In der zweiten Projekttphase (Implementierungsphase) werden bei den Industrieunternehmen die Innovationsprozesse als Pilotprojekte nach dem AIDA-Ansatz durchgeführt. Die entwickelten Maßnahmen sollen dabei erprobt, evaluiert und optimiert werden. Im Vordergrund stehen dabei die Verfahren zur Selbstoptimierung, Selbstkonfiguration, Selbstdiagnose sowie der Informationsverarbeitung im Innovationsprozess.

Literatur

Anhang

<table>
<thead>
<tr>
<th>Nr.</th>
<th>TRIZ – Bestandteil oder Werkzeug</th>
<th>Anwendungsbereich</th>
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<tr>
<td>1</td>
<td>40 Innovationsprinzipien zum Überwinden technischer Widersprüche; Widerspruchstabelle.</td>
<td>Leichte bis mittelschwere Erfindungsaufgaben.</td>
</tr>
<tr>
<td>2</td>
<td>System von abstrahierten Standardlösungen der Erfindungsaufgaben: 5 Klassen/76 Standards;</td>
<td>Leichte bis schwierige Erfindungsaufgaben.</td>
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<td>4</td>
<td>Methode der Stoff – Feld – Strukturanalyse technischer Systeme.</td>
<td>Abstrahierte Analyse technischer Systeme; Arbeitsmittel für Nr. 2 und 3.</td>
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<tr>
<td>5</td>
<td>4 Gruppen von Separationsprinzipien</td>
<td>Überwinden physikalischer Widersprüche. Werkzeug von ARIZ (Nr.3).</td>
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<td>Datenbank physikalischer, chemischer, geometrischer Effekte und ihrer Anwendungen in der Technik.</td>
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</tr>
<tr>
<td>9</td>
<td>Antizipierende bzw. vorausschauende Fehlererkennung (AFE) in technischen Systemen.</td>
<td>Spezielle Methode zur Analyse und Vorhersage möglicher Fehlerszenarien.</td>
</tr>
</tbody>
</table>

Tabelle 2: Wichtigste Bestandteile und Tools der klassischen TRIZ-Methodik (Livotov, 2002).