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Constraint-Dominated Breakthrough Innovation in a Manufacturing Process Situation

(A Case Study From the Photographic Paper Manufacture Industry)

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Abstract

All systems hit limits. All attempts to try and improve a system that has hit its fundamental limit are destined to fail. In such situations, additional improvement can only be achieved by making changes to the system. Changing a system – particularly a manufacture process that may have commissioning costs measured in millions of Euros – can imply significant risk and expense. In the paper we discuss strategies designed to help engineers to ensure that effective change can be made with the minimum impact on both parameters. The paper uses a real industrial situation from the photographic paper and film manufacture sector, and concludes by showing quantifiably significant bottom-line improvements to the manufacturing process under investigation

Introduction

One of the philosophical pillars of TRIZ is the idea that all systems will evolve in the direction of an ideal final result. In this ideal final result, the desired functions will be achieved with zero cost or harm. Although there are many instances where this end goal has been attained (Reference 1), it is generally used as an *attractor* for innovative efforts; successful innovations should deliver a more ideal solution than the solution they are going to replace.

The dynamics of evolution further dictate that the route from an existing system to the ideal final result state is a non-linear one. Evolution occurs through a series of disruptive shifts as one system hits its fundamental limits in the form of a conflict or contradiction, and then another one emerges which successfully challenges those conflicts.

As illustrated in Figure 1, TRIZ gives us three principle mechanisms for accelerating this evolution dynamic– we can solve contradictions, find other ways of delivering functions, or we can use the trends of evolution.

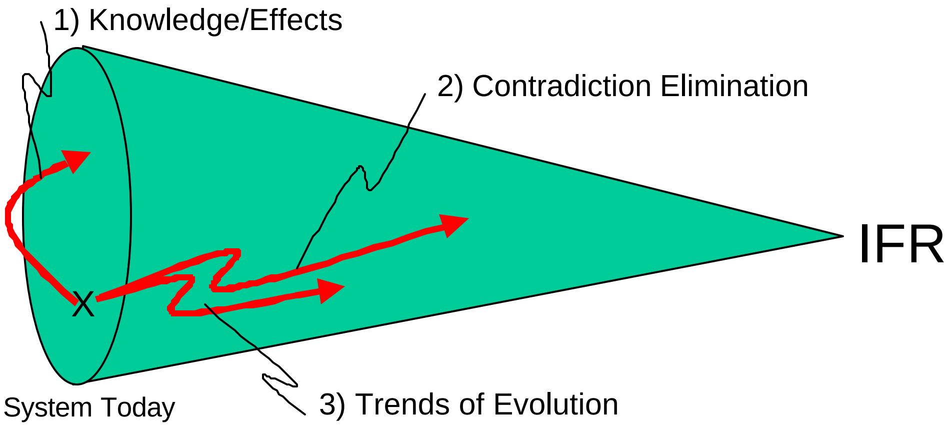
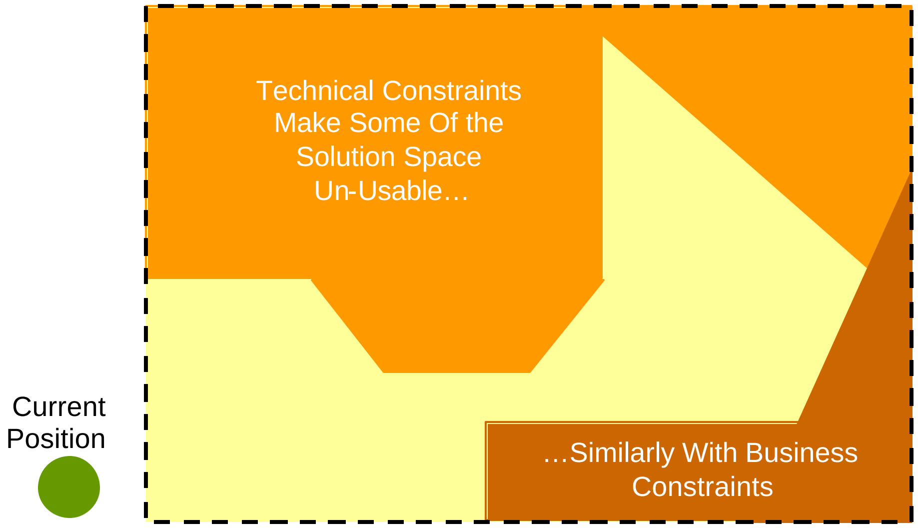


Figure 1: Three Principle System Evolution Mechanisms

Any successful breakthrough strategy must, of course, fit within the real-life constraints imposed on the prevailing situation. Constraints can very easily transform a solvable problem into one which is not. This is especially evident when we take into account the implication from the conical image presented in Figure 1 that the evolution process is convergent.

If we imagine that it is possible to define a space within which all solutions lay (for example the dotted box illustrated in Figure 2), then we may see the constraints as the things defining regions of that solution space where we can and cannot go. As suggested in the Figure, the constraints can be either technical in nature (e.g. 'the energy consumption must be less than x') or they may be 'business' (time, money, people, ethical, etc).



complete solution space – the ideal solution to a problem must lie within this area

Figure 2: Constrained Evolution

What this image suggests is that if our evolution path from the current position to Ideal Final Result is blocked by our constraints, then advancement of the system will be prevented.

As reported in Reference 2, in manufacture processes the constraints are often very heavily dominated by the amount of investment sunk into the procurement of expensive machinery. Reference 3 also goes on to report that this is a major reason why so many innovations come from newcomers and not incumbents – the newcomer simply has no previous investment to write-off. What this should tell us is that smart process industries will manage their constraints well and will be planning for disruptive jumps in their capital equipment.

Reference 3 provides a demonstration of how the idea of constraint management can be used in conjunction with the trends of evolution part of the TRIZ toolkit. In this paper we will focus on the management of constraints in relation to the function database and contradictions parts of the toolkit.

Background

A process for manufacturing a chemical in the photographic process has always been used in considerable quantities. During the past 5-6years the demand for photo products has reduced as the digital imaging market has rapidly grown in size. This has meant that previous batch sizes are too large and new ways of manufacturing must be found in order to keep the manufacturing process economic. There is also the issue of inventory and product shelf life with the original size batches. An approach from the production department was made to ask for a manufacturing process that reduced the batch size from 106kg to 50kg. A small group of engineers and production technologists were brought together to investigate ways to achieve the production requirements, with only one person in that group having used TRIZ.

Initial Investigation

An initial investigation revealed a number of other issues that were of a consequence in the manufacture of this chemical.

1	Batch size	106kg
2	Chilling time	2hours
3	Mixing time	30mins.

The operators felt that the chilling time and cooling time were also excessive and that if there were a reduction in these parts of the process it would free up the vessel for other work.

The ideal final result for each of the three critical process parameters, was readily seen as, respectively, 0kg, 0seconds and 0seconds. The ideal final result (IFR) idea forces us to put constraints to one side. In some instances, we can use the IFR to force ourselves to develop some very effective solutions. In this case – like many others – however, the constraint of having a large amount of existing equipment and lack of capital budget to replace them prevented us from using the IFR definition as anything other than an attractor. In situations like this – where the constraint prevents a big change – we are forced to analyse the existing system.

The System

The whole system was sketched and the question asked as to whether the various components contributed to the reason for the long chill time, the extended mixing time or the need for such a large batch. This approach allowed us to reduce the components that were to be analysed and a function diagram was produced. Figure 3 illustrates a simplified version of the resulting function analysis model.

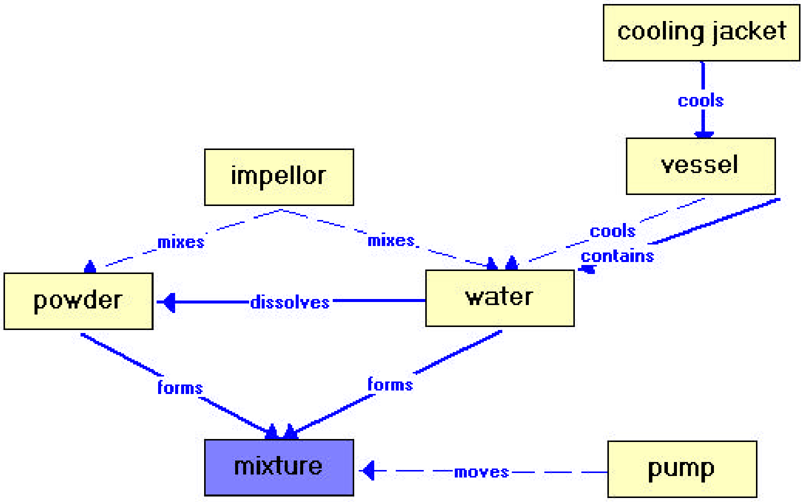


Figure 3: Simplified Function Analysis Model For System

Manufacturing Process

The manufacturing process was relatively straight forward consisting of the following steps:

1	Add water to vessel	
2	Allow water to cool	2 hours
3	Add powder to water	
4	Mix with Impellor	30 minutes
5	Open bottom outlet valve	
6	Pump away mixture	

The group now asked three questions

1 Why could the batch size not be reduced?
2 Why did the cooling take so long in a jacketed vessel?
3 Why did the mixing take so long?

The following answers were given or found out during the investigation:
The batch size was actually less than it should have been. When viewed from the additions box on top of the vessel it was clear that the 106kg only just came into contact with the bottom of the impellor. The operators then explained that the impellor required the water to be above the impellor as it was used as a lubricant of for the bearing supporting the impellor on its shaft.

The second answer that became very clear was that because the batch size had been reduced to its 106kg it was now below the level of the cooling jacket. It was only by the fact that the steel shell gradually cooled down that the water that it contained also cooled down.

The third and final answer showed that due to previous attempts to reduce batch size it was now so low in the vessel that much of the rotation of the impellor was completely wasted as only air was being entrained into the fluid and not the powder.

The group were keen to forge ahead with the purchase of a new impellor suited to the size of batch but after some discussion it became clear that this would not answer the greatest bottleneck in the process which was the initial cooling of the water from its ambient temperature down to the temperature required by the process.

More detailed questions were now asked as to what was stopping the various problem areas from being improved.

What is stopping the operator from reducing the batch size?
The bearing will no longer get any lubrication and therefore overheat and fail
What is stopping the operator from reducing the chilling time?
The fluid is not in contact with the part of the vessel that is very effective at chilling
What is stopping the operator from reducing the mixing time?
The fluid does not adequately cover the impellor

Contradictions

This kind of 'what would I like to improve/what stops me from making the improvement?' questioning is a very simple and effective way of identifying the contradictions within an existing system. From the above knowledge it was easy to begin to list a set of conflict pairs:-

I want to reduce the batch size but bearing overheats
I want to reduce the batch size but mixing does not occur
I want to reduce the batch size but chilling time is increased
I want to reduce the batch size but air is introduced into the solution

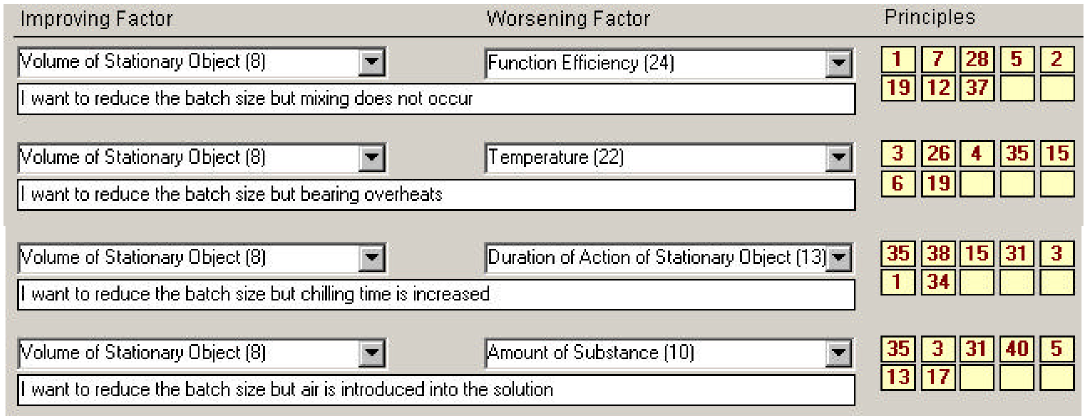
The conflict pairs could also be transformed into physical contradictions:

The water level must be low for a good batch size but must be high for efficient chilling
The water level must be low for good batch size but high for good lubrication
The water level must be low for good batch size but high for good mixing

In other words we really want the water to be at the top of the vessel for one operation and at the bottom of the vessel for another operation.

Having identified conflicts, the matrix was consulted to see what inventive principles might be used. We decided to use the new 2003 version of the Contradiction Matrix (Reference 4). As there were several contradictions present, we also used the CREAX Innovation Suite to allow us to examine multiple contradictions simultaneously. The software will automatically identify and prioritise the sequence of Inventive Principle suggestions.

Note that we used the parameter ‘volume of stationary object’ rather than ‘moving object’ because the focus of the contradictions was on the static part of the system – the vessel. The positions of all of the functional elements contained within the vessel were fixed, and only the fluid was capable of relative movement.



Improving Factor	Worsening Factor	Principles
Volume of Stationary Object (8)	Function Efficiency (24)	1 7 28 5 2 19 12 37
I want to reduce the batch size but mixing does not occur		
Volume of Stationary Object (8)	Temperature (22)	3 26 4 35 15 6 19
I want to reduce the batch size but bearing overheats		
Volume of Stationary Object (8)	Duration of Action of Stationary Object (13)	35 38 15 31 3 1 34
I want to reduce the batch size but chilling time is increased		
Volume of Stationary Object (8)	Amount of Substance (10)	35 3 31 40 5 13 17
I want to reduce the batch size but air is introduced into the solution		

Figure 4: Conflicts Mapped To New Matrix

For the physical contradictions a series of questions about the process were asked to decide which separation principles should be used.

Where do I want the water to be high?	On the inside of the vessel
Where do I want the water to be low?	On the inside of the vessel
When do I want the water to be high?	For chilling
When do I want the water to be low?	For mixing
I want the water to be big if?	I’m chilling
I want the water to be small if?	I’m mixing

This suggests that either the separation in time or separation upon condition principles could be used. This in turn leads us to a selection of Inventive Principles that could be used to challenge the contradictions present.

Resources And Constraints

At this point, it would have been possible to begin using the Principle recommendations to begin generating solution ideas. The conflict and contradiction analyses, however, had generated a large number of possible Principles, and it was felt that it would be better to try and manage the process more tightly. At this point, therefore, we returned to our problem definition activities and reviewed the resources and constraints present in the system. The idea here was to identify which of the Principles were consistent with what we had available, and what we could and could not do.

Firstly we reviewed the untapped resources available in the system and whether it would be possible to use them in the quest to reduce batch size, chilling time or mixing time.

Plant Resources

- Vessel
- Chilled water
- Vessel jacket
- Pump
- Agitator
- Impeller
- Bearing
- Bottom outlet valve
- Inlet ports on top of the vessel
- Water feed pipe

Turning the problem around the question was also asked if it were possible to lift the bottom of the vessel to make the water contact the chilling jacket. Or how would you raise the water to be in contact with the walls of the vessel for chilling but at the bottom of the vessel for mixing.

Constraints

The primary constraints present in and around the system primarily related to money: It seemed immediately obvious after having defined the contradictions that many of them would be eliminated completely by completely re-designing the arrangement of components within the vessel. Financial limitations precluded the construction of such a new design.

Other constraints present were:-
* physical size should not be increased since available space outside the vessel was limited
* energy consumption should not increase
* there should be no possibility of affecting the quality of the product – several downstream processes had been optimised around the product in precisely its current form.

Both resources and constraints were then used as a means of down-selecting the Inventive Principles that could and could not be used to help generate solution directions.

Resource/Constraint	**Principles Eliminated**
Product must not be affected	35 – Parameter Changes 38 – Enriched Atmosphere 34 – Discard & Recover 40 – Composite Materials
Existing Hardware	26 – Copying 37 – Thermal Expansion 6 – Universality 40 – Composite Materials 7 – Nesting
Energy consumption	36 – Phase Transition

Care was taken to only ‘eliminate’ Principles that were clearly outside the scope of the boundary conditions. Thus, although Principle 13 – recommended by one of the conflict pairs – appeared to be inconsistent with the constraint about not changing hardware, we could see several places where it could potentially be used by elements within the system. Principle selection, in other words, was made on the basis of zooming-in and zooming-out on the system, and examining it from different perspectives.

At the end of this ‘constraint management’ analysis, we were left with the following remaining Inventive Principles (in descending order of likelihood – as determined by the sequence present in the Matrix):

3, 1, 31, 15, 28, 4, 5, 19, 2, 29, 13 and 17

With this information to hand a brain storm on the Inventive Principles and resources available was carried out. Initial focus was placed on the pump since this was felt to be the most under utilised item in the plant: The pump was only used at the end of the cycle for emptying the vessel and sat stationary for more that 90% of the manufacturing process and it would also answer the question of how do you raise the water to be at the top of the vessel for chilling. The pump thus looked like a possible untapped resource capable of offering an answer to the Other Way Around direction suggested by the conflict analysis.

Implementation

A valve was fitted into the pipeline from the pump and a bypass line fed back through the inlet port on top of the vessel and directed towards the wall of the chilling jacket.

A test was conducted with a 106kg batch of water and found to chill the water in 45mins which was a major step forward in reducing cooling time. However, it still did not answer the issue of batch size.

The group went back to the resources and reviewed what could be done for mixing and batch size. Again the pump operation came to light as a source for mixing so the impellor was turned off during a trial and the re-circulation of the fluid was carried on after the chilling phase of the process.

The mixing process still took as long with this method.

At this point the groups hand was forced somewhat as the bearing on the existing impellor failed and we were faced with a £3500 bill to replace the unit. We took the recommendation of Principle 28, Mechanics Substitution as a prompt to see if it were possible to achieve the mixing function delivered (albeit not very well) by the impellor with a non-mechanical means. (Note that if the impellor bearing had not failed, the chances are we would not have thought so much about this Principle as it appeared to be offering a highly non-instinctive solution direction.)

Further analysis suggested the segmentation principle (1) for the fluid flow and also using the pneumatic /hydraulic principle (29) in mixing.

This now presented a further physical contradiction of wanting the feed pipe to be high for the chilling and low for the mixing. A solution to this contradiction was achieved by splitting the feed pipe into the top of the vessel into two parts. One fed to the sidewalls and the other went down to the bottom of the vessel. Another example of Principle 1, but also elements of Principles 3, 4, and 17 were incorporated into the eventual solution.

With these solutions, we now found that by having the pipe feeding to the bottom of the vessel we could reduce batch size considerably.

Next, the feed pipe for the chilling part of the process had a spray device added to its end – yet another interpretation of the segmentation Principle. This allowed the surface area of the water hitting the sides of the vessel to be greatly increased.

Further analysis of Principle 17, Another Dimension, guided us to turn the bottom of the pipe by 90°. This generated a rotating motion of the fluid in the bottom of the vessel. Judicious positioning of a simple fixed plate against which the fluid would be forced impinge further increased the mixing capability. We noted for future use the possibility of further improving mixing by adding holes to this plate – as was suggested by Principle 31.

Results

After incorporation of all of the recommended solutions, the following results were obtained:

Chill time with the spray nozzle system now	less than 15 minutes
Mix time with pump and pipe system	less than 15 minutes
Batch size reduced to	less than 50kg

The benefits corresponded to a doubling of batch size flexibility, a five-fold reduction in overall process time, and the complete elimination of a difficult and expensive maintenance operation.

Conclusions

This case study showed that it is possible to introduce the techniques of TRIZ into an inexperienced group and obtain excellent results.

TRIZ forces users to focus on untapped resources in systems. Like nearly all systems, the one involved in this case study was seen to contain a lot of untapped potential. This happens because TRIZ has examined all areas of technology, and thus accelerates the possibility of transferring the good ideas that have been developed in one sector to others. As such, we might see TRIZ as offering a global benchmarking capability.

The case study demonstrates how the contradictions part of TRIZ can be used to alleviate bottlenecks in manufacturing processes. All systems eventually hit limits. Exceeding these limits fundamentally requires some form of change to the system.

What we have demonstrated here is a process of using resources and constraints to determine which of the TRIZ solution generation components are more likely than others to help generate real solutions. That process is designed to be flexible. Its essence is described in Figure 5. According to the Figure, we can use the Contradiction parts of TRIZ to generate a list of Inventive Principle suggestions. We can then use our resources and constraints to determine which of these Principles is likely to point us towards solutions consistent with those constraints. There is no absolute ‘need’ to do this of course, but when the range of contradictions is broad – as it was here – and the number of Inventive Principles recommended is high, a constraint management process can do much to reduce the time required to generate viable solutions.

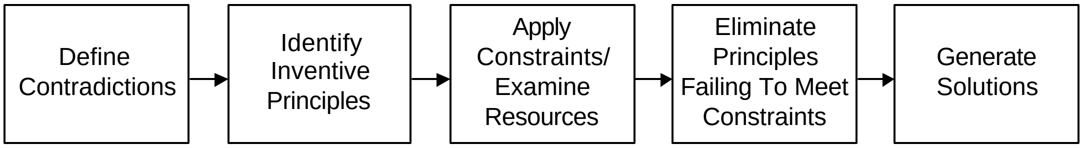


Figure 5: Constraint Management Process

Exactly the same process applies during the use of other TRIZ tools; constraints and resources will dictate which of the solution directions suggested by Trends, Effects/Knowledge, etc will or will not offer viable solutions.

As we could see in this case study, very often the resolution of one contradiction generates others. This is fundamental to the idea of Contradiction Chains (Reference 5). One of the main ideas behind the contradiction chain idea is that system evolution takes place through resolution of a succession of conflicts and contradictions. Very often we will hear things like ‘ah, but, I can’t implement that solution because of x’. TRIZ is trying to suggest to us that whatever x might be, someone, somewhere has already solved that problem. In other words, do not give up after the first attempt to solve a problem has hit an obstacle. In this regard, we also note that there are still Inventive Principles recommended for our contradictions that have not as yet been implemented in the solution. This suggests that we still have significant untapped potential to evolve and advance the new process.

A strong evolution driver in most process operations is reduction of the cost and harm aspects of the ideality equation. Both of these drivers will influence which of the TRIZ solution generation triggers can be deployed. Principles and trends associated with reducing part count are thus particularly relevant in these types of problems. In all processes we are aiming to produce more with less. The IFR attractor says that ultimately we want everything from nothing.

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