Identifying Discontinuities for Strategic Research

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Biography

Jack Hipple is Principal with Innovation-TRIZ, a consulting firm focused on organizational problem solving and specializing in the use of the breakthrough problem solving process known as TRIZ ("Theory of Inventive Problem Solving"). He graduated from Carnegie Mellon University with a BSChE and spent 30 years in the chemical industry prior to starting his own consulting business in 1999. His industrial career included responsibility for Dow Chemical's Discovery Research program and its global chemical engineering laboratory, project management responsibility for the National Center for Manufacturing Sciences, and new product development responsibilities for Ansell Edmont and Cabot Corporation

Abstract

R&D and technology planning frequently is done via extrapolation of past businesses and technologies, using the core competencies of the existing organizations. Occasionally, this results in disastrous consequences when a given technology is totally displaced by a technology totally foreign to the organization. An everyday example would be the evolution of "image capturing" from etching to painting to printing to wet chemical photography to electronic photography. Each of these approaches uses different skills and competencies and significantly different technical approaches.

When one studies the evolution of intellectual property, a predictive set of technology development lines can be seen, which are predictive and allows strategic, R&D, and personnel planning that stays one step ahead of discontinuities and anticipates them. These patterns of evolution are a key part of the TRIZ "Inventive Problem Solving" process the principles of which have been derived from the study of millions of the world's most inventive patents. This allows an organization to plan much more effectively in terms of budgets, types of technical disciplines needed, and types of customers and potential customers with which to partner.

etc. the mental process changes in a very sadistic, but productive way. When asked to figure out how to make a process release hazardous materials *all* the time and cause loss of human life, and an environmental catastrophe, a group will not only find many more possibilities, but will have fun doing it. This presentation will review several major incidents from this perspective and demonstrate how this technique could have been used proactively to improve the process design and minimize the potential for the disasters that happened.

HISTORY AND BACKGROUND

In the 1950's an insightful Russian inventor and patent examiner named Genrikh Altshuller, after analyzing hundreds of thousands of breakthrough patents, determined that there was a basic inventive algorithm that could solve virtually any significant engineering problem. He also found there were similar and a limited number of generic inventive principles used across all areas of technology. This work led to "TRIZ" (Russian acronym for "Theory of Solving Inventive Problems"). Altshuller and his colleagues continued their work, continuing to develop these algorithms through the 60's and 70's. TRIZ emigrated from the former Soviet Union to the United States, Europe, and Japan in the late 1980's after Perestroika and is now in use by many Fortune 500 companies to solve difficult problems, improve intellectual property filings, and accelerate the pace of internal innovation. Major users include Motorola, Dow Chemical, Unilever, Siemens, Intel, the US Navy, British Petroleum, and Hewlett Packard. AIChE and ASME currently offer public courses in this methodology[5]. The technology has been extended in its application to not only technology applications, but to business problems, human factors and ergonomics, biological systems, and intellectual property filing and circumvention. Over time, the continued analysis of patents and inventions also showed that there repeatable patterns of technological evolution which could be used to not only predict next steps (sometimes very discontinuous) in technological evolution, but also assist with strategic planning and acquisitions.

TRIZ Lines of Evolution and Examples

In the study of the patent literature, it is possible to identify lines and patterns of evolution that occur repeatedly and are seen across a wide range of technologies. Some of the ones Altshuller and his colleagues identified are as follows:

1 *Systems and products become more ideal over time*.

This implies simpler products and systems, functions which don't require a product or system at all, or the addition of useful complexity to an existing system. It can also mean the elimination of a part of a system and having the function which was being accomplished via that part achieved through another or combination of other elements, eliminating the need for a given part. In the TRIZ world, this is commonly referred to as "trimming". Another approach to a system becoming more idea is the identification and use of resources previously unidentified, especially those that might be inexpensive or normally considered detriments to the system.

Consider the simple example of tank trucks used for chemical transport. With DOT regulations and a simple colored and numbered placard on the truck, an emergency responder immediately knows the general nature of the materials in the truck and has a general feel fore how to respond to a spill.

Example illustrating the "trimming" concept as well as the use of existing resources would be the Black and Decker paint stick as well as traveling toothbrush. Both use the hollow space (unused resource) within a handle to replace, in one case a paint pan, and in the other a toothpaste tube. Note that these two examples, illustrating the same inventive principles, are from two totally different industries and were years apart in their commercial introduction. Note also that using the handles as holders for materials also reduces the use of plastic in the handles' manufacture.

2. *Systems and products become more dynamic with time.*

Dynamism can mean many different things, but in this context, it means more responsive to conditions or needs of the user or system at any given point in time or under any condition.

Examples of this line seen in the chemical industry are variable speed pumps and drives, variable process control systems whose set points vary with process or external conditions, systems that change color to indicate a condition, and alert warning levels which increase with severity of weather or process conditions.

In the everyday world of automobiles, we see brakes whose action are proportional to road conditions such as surface moisture, radio volumes that automatically adjust to external noise and car speed, and seats that adjust automatically to the driver's key. Of course, all of these also make the car more ideal from the driver's viewpoint.

3. *Systems oscillate between simplicity and complexity*

This line of evolution describes a phenomenon often seen as products and systems evolve. A simple device or system is invented that serves a new need or serves it better than another product or system. We then begin to add "useful complexity" in the product or system to make the product more valuable (and potentially raise the price). Then, as we add complexity, the ability to use the product or process becomes problematic. Finally someone finds a simplicity breakthrough and the cycle stars again. A simple everyday example of this is the copier. Additional functionality such as reducing and enlarging as well as faxing are now commonplace. Unfortunately many of these systems are now so complex that only the most experienced office assistant knows how to use, and the exercise of making just a few black and white copies becomes a daunting task. These individuals now have simple black and white copiers in their office to avoid the complexity, or as in the first line cited above, do without copies and traditional storage and mailing via Emailing and electronic storage.

In the chemical industry, we can look at

4. *Evolution with Matching and Mismatching Components*

5. *Evolution Toward Micro-level and Increased Use of Fields*

This is an expression of the fact that products and systems evolve along a field evolution line:

a. Mechanical field

b. Thermal and acoustic fields

c. Chemical fields

d. Electronic fields

e. Electromagnetic fields

Examples

Assuming that we have successfully completed the first three steps of this analysis (ideal result, inverted ideal result, exaggerated inverted ideal result), we look at time, space, fields, field conversion, substances and materials, time, and information as resources that can be used to accomplish this extreme negative situation. Let's look at an example of each.

Time as a Resource for Failure

The CCPS Process Safety Beacon in CEP Magazine (January, 2006) presented a summary entitled "Time Sensitive Chemicals", highlighting the fact that many chemicals have shelf life limits and become unstable or reactive with time in storage. Inhibitors in monomer storage systems have time limits as they are consumed. In principal, this is no different than freshness dates for food in a grocery store. In the sense of this methodology, we would ask, "How much time do we need to allow decomposition? How would I MAKE SURE that this amount of time is available?" The answer may lead us to look closer at process storage, inventory, shipping delays, as well as customer inventory time. Some of these segments may be seen by a checklist review, but if we focus on HOW to create the time, we will tend to see more possibilities, such as changes in the customer's inventory (not just our own). We would more appropriately consider the relationship of time and temperature. Slow rail deliveries in an excessively hot summer may result in consumption of an inhibitor. This has been the case in styrene polymerizations within rail cars.

In a previous example presented at the 2007 CCPS meeting[4], the rupture of a hazardous chemical drum shipment was traced back to a long overseas transport time, allowing a corrosive reaction (iron plus bromine) sufficient time to generate enough heat and pressure to go beyond the pressure rating of the drum. The combination of time, extremely low heat capacity (0.1 vs. water's 1.0), and the heat of corrosion contributed to a dangerous release of bromine.

In an ethylene oxide explosion[3], long standing rust (a polymerization catalyst) in a dead spot (*time!)* had accumulated. How can we *make sure* that we can accumulate reactive materials? How would we design a piping system to do this? Then don't do it!

We frequently recognize time as a potential problem area, but we don't often exaggerate its impact as we do with Predictive Failure Analysis©.

Materials as Resources for Failure

We are generally aware of the potential consequences of mixing the wrong materials together, but we sometimes forget that normally "non-hazardous" materials can create danger, if combined in the wrong way. We also recognize in general the hazards of confined spaces. The combination can be deadly. CCPS reported this past August on the death of a worker using a sheet of black plastic to shield a black light to inspect piping. 150 feet away an open nitrogen line put enough nitrogen into this "closed" space, causing asphyxiation. The checklist approach did not consider checking this possibility. Suppose we had used this type of analysis in this case. We would ask the question, "How can be *make sure* there is no breathable air within this space? Are there any materials nearby that might allow this to happen? How would we *make sure* that nitrogen was introduced into this space? Where is there nitrogen?" The source would probably have been identified and eliminated.

In the previously mentioned bromine release case, the material being shipped and the material from which the drum was constructed were material resources for a runaway reaction beyond the obvious corrosion reaction concern.

In another well publicized case, an explosion within a kerosene tank containing a water layer was traced to bacterial action generating methane which was the source, combined with a welding torch, for an explosion. The checklists used did not catch this, but if we had asked the question, "How would I make sure that a flammable gas was generated in the tank? What would be required? Is it possible to generate the materials?"

Substituting steel and titanium in dry and wet chlorine service is a frequent materials mistake.

Information as a Resource for Failure

Since virtually all of our processes measure and respond to information generated by a variety of sensors and instrumentation, it is important to consider there normally "good" resources and how they can be used in a negative way. In the now famous Texas City fire and explosion, a column level indicator showed level decreasing at the same time the column was overflowing. This occurred because the instrument was submerged and under those conditions, density was being measured, not level. As the temperature rose during column heat up and recirculation, the level "indication" (not the actual level) actually decreased whereas the column was actually overflowing. A back up level indicator failed to respond. Consider how things might be different, if during a safety review we had used this Predictive Failure Analysis© process instead of the normal HAZOP approach. We would have asked, "How could I *make sure* that we were *never* aware of that the level was? That the level indication was *never* correct?" It is probable that someone, during the review, would have suggested that, if the fluid level in the column was higher than the maximum level indication, the level indication would be meaningless and potentially dangerous. It might also have been suggested to find a mechanism to determine the status of any backup instrumentation.

The general question to ask is "How Would I *make sure* that my process instrumentation readings are incorrect *at all times?"*

Unavailable or unknown information causes the same potential for disaster. If explosion potential or explosive ranges are simply not known, the most well intentioned HAZOP team will not take precautions.[3]

Energy as a Resource for Failure

This is an area which we normally consider. We usually think about obvious and visible energy sources such as furnaces, steam, heat transfer fluids, hot water, gas, and electrical sources. In some cases, however, we miss the energy produced by internal processes and the accumulation of energy in ways and places not expected. In a 2005 acetylene cylinder facility explosion in Perth Amboy at Acetylene Services[5], a failed check valve allowed a flow of acetylene backward from a calcium carbide/water reactor into the water supply line and ultimately into a closed space which contained a space heater. Now consider if we had asked, "How can we *make sure* that acetylene flows backwards? How could we make sure that, if this happened, it would concentrate in a confined space? How would I *make sure* that, if this happened, there would be a source of ignition? Why not put a space heater in the space? This was well intentioned to keep operating personal warm in a water area that was never expected to contain acetylene.

The approximately 200 dust explosions in the last decade in the US have been analyzed by the Chemical Safety Board[5] and two key aspects have been pointed out. First, in addition to the traditional fire triangle, it is required to have dust concentrations be elevated and in a confined space. These are mechanisms for concentrating the energy of dusts. Then something disturbs the settled dust is dispersed and ignites. In analyzing our processes, we can ask the simple question (in addition to all the traditional ones), "How can we MAKE SURE that dust concentrates?" Inadequate ventilation? Cleaning? How can we MAKE SURE that we have a confined space for dusts to accumulate? How can we MAKE SURE we have both? How can we *make sure* that there is *always* an ignition source present?

In the 2005 Praxair gas cylinder storage explosion, energy sources came from the sun (it was an unusually hot 97 degrees in late spring) and hot asphalt, the combination of which was sufficient to overwhelm the pressure relief valves in the cylinders. We often think about the sun and asphalt as things that are just "there"—part of the facilities and background, but from a TRIZ analysis perspective, they are resources, and they can be energy sources. If we had asked the question, "How can we *make sure* that there is sufficient heat to heat the cylinders sufficiently to release gas?" it is possible that we might have thought about shielding the storage area or painting the surface with a reflective coating. We might have calculated more thoroughly the heat transfer and relief valve limitations of the system.

Fields as a Source of Failure

Basic fields include thermal, chemical, magnetic, electronic, acoustic, electromagnetic, and biological. The potential impact of recognized fields is normally considered in our check listing, but frequently field conversion is not (see next section). Unrecognized fields are the concern. The simple way to do this is to take this list and ask "is the field present?" If so, what are the consequences? Next, ask how could I generate such a field if it is not recognized as present already? Then, what are the consequences of this field's presence? We can use Table 1 as a template for doing this.

Table 1

Field Source Worksheet

Field	**Present? (Y/N)**	**If No, how to produce?**	**Potential Consequences**
Mechanical			
Thermal			
Chemical			
Electronic			
Electromagnetic			
Acoustical			
Pressure			
Acoustical			
Human Behavior			

Note that we have included "human behavior" as one of these fields. We have many automated chemical plants that we assume are not impacted by human behavior, but as we see frequently (and was the case in the PB fire and explosion) that humans can turn off alarms and ignore them. The question to be asked here is how could we *make sure* that an alarm or warning was ignored? How would we make that happen *all the time?* What resources are required? Are they present? Can they be created with the resources present? In the case of human behavior, we can think in terms of conflicting data presentations, parallel job responsibilities, personal experience and past history of false alarms, etc.

Forcing ourselves to create these various fields is a more comprehensive approach than simply asking ourselves whether they are present or not. Like an ignition source in a fire, we seldom know what it was, but it's always there. This is not to imply that all these fields and sources of energy are everywhere at all time, but to say that we frequently get blindsided by our narrow vision of the process environment.

Field Conversion as a Source of Failure

There is almost an endless list of field conversions. Chemical fields (reactions) generate heat, electrical fields generate both thermal fields and magnetic fields, and magnetic fields generate electrical fields. Chemical fields (reactions) are produced by electrical fields, both producing thermal fields. Mechanical fields (friction, rotating equipment, etc.) all produce friction, heat, and static. Static (an electrical field) is an ignition source for gases and liquid vapors. We know most of these facts. In the use of TRIZ in conventional problem solving, we usually are looking for field conversion in a positive sense, i.e. we are looking for potential resources for problem solving. In failure prediction, we are looking at the opposite: the potential consequences of these field conversions from a negative standpoint. What new fields can be formed and how could these new fields cause harm and damage?

As an example, the corrosion of materials is normally considered a nuisance or quality problem, and a factor that we use to choose materials of construction. However, corrosion is a chemical reaction and as such, has thermal effects. In the aforementioned bromine drum rupture, the concern was about the drums leaking a hazardous, corrosive material and causing personal harm and injury. The drums were properly designed (i.e. wall thickness) to withstand the corrosion rate over the intended time. However, they were not pressure vessels and were not designed to withstand the pressure generated from the liquid turning into a gas from the heat of corrosion. Aggravating this situation was the extraordinarily low heat capacity of liquid bromine (0.1 vs. water's 1.0). The combination of these two things in combination with the drums being overfilled, caused the hazardous has release. Again, if we had asked ourselves, "How could we *make sure* the drums ruptured in transit?" we would have said overfill them, let them sit in a hot Houston ship channel, and not properly calculate the heat balance on the drum during transport. In another case, corrosion of steel in an evaporator waiting to cool prior to vessel entry removed sufficient oxygen to produce a less than breathable atmosphere several hours after a vessel entry check had been performed, indicating safe entry. Several hours later, the maintenance worker entered the vessel without independent air supply and was immediately overcome and died before rescue was possible. This is an example of time, energy, and field conversion all contributing to a fatality.

In the BP raffinator tower explosion mentioned previously, the filled tower's thermal field applied unknowingly to recirculating fluid was changing the density of the fluid and affecting the mechanical force on the level indicator. Basic laws of physics tell us that no field can be used or generated without their being one or more accompanying fields. One of our responsibilities is to make sure that we are aware of all the potential byproduct fields a field, process, system, operation, or movement can produce and then methodically step through the consequences of these additional fields on our processes, equipment, instrumentation, and control. A simple table for doing this is shown in Table 2:

Table 2

Field Conversion Worksheet

Original Field	**Byproduct Field 1**	**Byproduct Field 2**	**Potential Consequences**
Mechanical			
Thermal			
Chemical			
Electronic			
Electromagnetic			
Acoustical			
Pressure			
Optical			
Human Behavior			

There are TRIZ (and other) handbooks[1,2] summarizing these field conversions, some of which are unknown in a practical everyday sense. Usually, in traditional TRIZ problem solving, we are trying to identify fields that can be cleverly used for solving a problem; in this case we are looking for by-product fields in a negative sense.

Some of these field conversion effects can be subtle and difficult to recognize and that is why it is critical to exaggerate our thinking in this process. Compressed air is frequently dried and purified through the use of molecular sieves. Nitrogen is preferentially absorbed and an enriched stream of oxygen is produced initially[3.] If an enriched oxygen stream is a hazard, this needs to be considered. This is a case of a chemical field (adsorption) producing a change in substance concentration, which can be considered as an enriched chemical field in terms of oxygen.

Note that human behavior has been included. This could include stress, long work hours, personal or family concerns, or supervisory/employee friction. The "byproducts" may not be traditional physical items, but certainly could include morale, attention span, and concentration. All of these have the potential to indirectly cause harm in a process through inattention, incorrect data collection and response, and incorrect decision making.

Space as a Resource for Failure

Insufficient space (confined space) is frequently cited as an accident cause. Using Predictive Failure Analysis© will not prevent doing things we already know are wrong or are not in compliance with known safety procedures, such as not using proper confined space procedures. However, space is a much broader term than this. It can be space around a system as well as space within a system (i.e. voids). It can be isolated spaces or dead spots in processing systems that can "hold up" materials for long periods of time (see previous section on time) and allow chemical reactions to proceed that are unanticipated.

A worker trying to clean tank residue was overcome by xylene fumes after a tank cleaning. Solids have voids (a space resource!) which can trap hazardous materials. Table 3 is an outline for use in evaluating space resources as resources for failures.

Table 3

Space as a Hazardous Resource

Type of Space Resource	**Is This Space Available?**	**Potential Consequences**	**How to Create?**
On the surface			
External, surrounding space			
Space inside			
Porous space inside			

Conclusions and Summary

Checklists and diagrams are useful and necessary, but they can be incomplete and the process for completing them can be boring when what is needed for safety thinking is stimulation and completeness. Deliberately trying to make a process, system, or piece of equipment fail produces possibilities that check listing by whatever mechanism, does not.

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