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Process safety improvement—Quality and target zero

Karl Van Scyoc *

Det Norske Veritas (U.S.A.) Inc., DNV Energy Solutions, 16340 Park Ten Place, Suite 100, Houston, TX 77084, USA

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Abstract

Process safety practitioners have adopted quality management principles in design of process safety management systems with positive effect, yet achieving safety objectives sometimes remain a distant target. Companies regularly apply tools and methods which have roots in quality and productivity improvement. The "plan, do, check, act" improvement loop, statistical analysis of incidents (non-conformities), and performance trending popularized by Dr. Deming are now commonly used in the context of process safety. Significant advancements in HSE performance are reported after applying methods viewed as fundamental for quality management.

In pursuit of continual process safety improvement, the paper examines various quality improvement methods, and explores how methods intended for product quality can be additionally applied to continual improvement of process safety. Methods such as Kaizen, Poke yoke, and TRIZ, while long established for quality improvement, are quite unfamiliar in the process safety arena. These methods are discussed for application in improving both process safety leadership and field work team performance. Practical ways to advance process safety, based on the methods, are given.

Keywords: Process safety; Kaizen; TRIZ; Poke yoke

1. Introduction

> "No great improvements in the lot of mankind are possible until a great change takes place in the fundamental constitution of their modes of thought. "
>
> *John Stuart Mill*
> *English economist & philosopher (1806–1873)*

Application of process safety principles has promoted significant reductions in disabling injuries, with many companies reporting lost workday cases one-tenth of that experienced only 10 years ago. The severity of major accidents, when they do occur, has been markedly improved by more sophisticated response activities. Various analytical tools, techniques, and approaches have been standardized to underpin the improvements in safety performance. Many companies express a corporate safety vision and in various forms: "No one gets hurt", "No harm to people", "Zero Tolerance Target Zero (0TT0)" reflecting the view that all accidents are preventable. While there has been very good progress toward this vision, many organizations are finding that the accident and incident rates are beginning to level off. This suggests that the gains made by existing activities are providing sustainable levels of performance, yet there remains the potential for further gains in pursuit of the corporate vision.

Often, improvements in a field of study are made through adaptation of methods in a related field. This paper explores several analytical methods that have been used for improvement of quality management systems. The following methods are examined:

- Kaizen: A method for applying continuous incremental improvement of business processes. This is an adaptation of the Plan-Do-Check-Act (PDCA) cycle.
- Poke yoke: A method for mistake proofing a product or process.
- TRIZ: A systematic approach for stimulating innovation in design.

For each of the methods, an overview of the history, approach, and traditional applications is given. Following that, discussion

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* Tel.: +1 281 721 6718.
E-mail address: karl.van.scyoc@dnv.com.

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of its possible application for process safety is described. Full treatment of the methods in the context of process safety cannot be achieved in a short paper; however, this discussion is intended to stimulate thought and encourage those seeking the objective of “target zero”.

2. Kaizen

Sometimes big events result in significant course corrections in safety management. Major process events have prompted very big leaps of industry safety practices, such as with the promulgation of the Process Safety Management (PSM)[1] Standard in the United States, which mandated a collection of activities following the 1989 Phillips Refinery incident which claimed 23 lives.

The industry response to PSM was to invest heavily in risk analysis, training programs, procedure development, emergency planning, and maintenance practices. This investment of capital and manpower produced a surge of improvement in technology and practices, with apparent improvement to safety performance regarding major accidents. However, some organizations lost momentum in their approach to managing major accident potential-growing complacent with the daily attention to risk controls. For some manufacturing sites, the safety shortcomings raised by Lord Cullen in the investigation of the Piper Alpha disaster of 1988 hold eerily true today:

- *“It appears to me that there were significant flaws in the quality of the management of safety...”*
- *“Senior management were too easily satisfied the permit to work system was being operated correctly...”*
- *“They adopted a superficial response when issues of safety were raised by others...”*

The direction of process safety has historically been set by industry events, but sustaining that progress and improving upon the approach may come from within the manufacturing organizations themselves. In the absence of major industrial events, significant improvements to process safety may be made through the combination of many small improvements in contrast to major change initiatives.

Kaizen [1–3] was designed to drive overall excellence through incremental improvements to work processes. It is a process based on improving quality, cost and delivery by the elimination of waste (muda). It is characterized by high-energy problem solving improvement teams that help ‘good ideas’ become reality.

Kaizen has its roots in post-WWII Japan when the economy was in shambles and product quality was shoddy. Toyota, among other manufacturing firms, was struggling to stay afloat and major layoffs were carried out. This shakeup left the businesses with reduced labor force and slim capital-consequently, a better way to do business was desperately needed. The resulting Toyota Production System borrowed from principles of statistical quality control of manufacturing processes, and embraced methods to reduce the waste in manufacturing. The Japanese further consulted with Dr. William E. Deming from the United States, who was advocating a continuous improvement process for quality management. This process is widely referred to as the Plan-Do-Check-Act model, Fig. 1, encouraging continual improvement and verifying that improvement is retained. Kaizen emerged as a fusion of the Deming continuous improvement process and the Japanese philosophies for management and manufacturing.

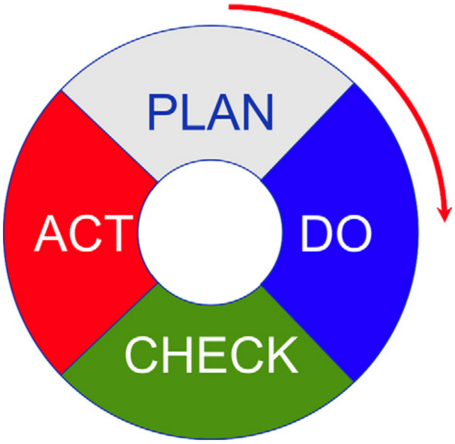

Fig. 1. Continual Improvement Loop, Deming.

The continuous improvement model, shown at right, forms the basis of the Kaizen work process. The intent of the improvement loop elements is given below:

- PLAN: Analyze information, solicit ideas, and select best plan for improvement.
- DO: Implement the plan (either as a pilot or fully deployed).
- CHECK: Gather information to verify that the desired effects of change are seen.
- ACT: Sustain gains made, make course corrections needed.

This improvement loop is well known among designers of safety management systems. The PDCA loop is imbedded as a part of the management system design, usually in connection with medium to long-term safety planning, implementation, and audit/review cycles. In Kaizen, the continual improvement usually takes place at the “shop floor”, where incremental change can be more effectively, and immediately, realized. A Kaizen Event may progress through the PDCA cycle in a matter of hours.

Kaizen is rarely used to “re-engineer” an organization, since this leads to significant disruption of an organization, where the seeds of distrust may be planted. The destabilizing changes in workforce, management structure, and labor agreements should be resolved prior to undertaking Kaizen.

Kaizen, in practice, takes many forms, but all seem to have the following attributes:

- Engagement of management and employees in teams, as peers, identifying possible improvement areas.

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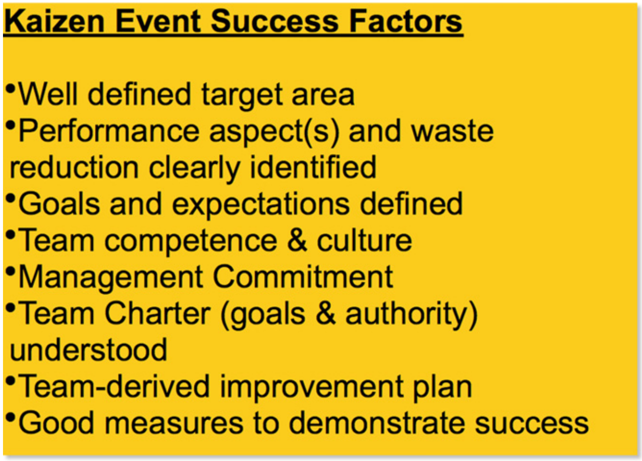
[1] 29 CFR 1910.119.

- Participative management, with decisions being made at the lowest possible level, by the individuals most affected by change.
- High level of trust with no-blame culture.
- Recognition, and acceptance, that there are problems.
- The Kaizen process is driven by facts and data, not by opinions.
- There is a formal walkthrough of the work process to identify sources of waste.
- The focus is on reducing waste (activities that add cost and provide no/limited value) and sustaining the gains, once waste is removed.
- Change is incremental and evolutionary—not revolutionary.
- Kaizen is both a philosophy and an approach.

The culture of Kaizen encourages immediate improvement to recognized waste. As such, some of the Kaizen benefit emerges through small changes in daily routines. For example, connecting two adjacent elevated platforms eliminates the requirement for maintenance or operations to scale two ladders. However, if there is rarely a need to access the platforms in the first place, there is little waste, and the cost of connecting the platforms may not offset the waste removed. These decisions and discussions may usually be addressed at the unit level, giving immediate feedback to the suggestion, while demonstrating value to the ‘customer’.

A more structured version of Kaizen, sometimes known as a Kaizen Event [2] is a facilitated team-event incorporating the Kaizen practices. A Kaizen Event has focus on a particular improvement problem, with specific expectations for waste elimination or reduction. There may be production interruptions as the Kaizen team fulfils its objectives (e.g. to evaluate inefficiencies in the production process), so adequate provision is made in inventory to provide assurance that customer deliveries are uninterrupted. Kaizen Events usually require 3 days to carry out. Initially the team pores over data, and through interaction in the work area, defines the work process as it actually is, rather than how it is assumed to be, Fig. 2. Areas for improvement are prioritized and a plan is presented to management for consideration. Once approved, the team oversees implementation and takes responsibility for the plan. Course corrections are made, again as a team, and progress measures are reported. Once sustained improvements are made the team charter is fulfilled. A celebration of success is arranged, and management recognition given to the team.



Kaizen Event Success Factors

- Well defined target area
- Performance aspect(s) and waste reduction clearly identified
- Goals and expectations defined
- Team competence & culture
- Management Commitment
- Team Charter (goals & authority) understood
- Team-derived improvement plan
- Good measures to demonstrate success

Fig. 2. Important Kaizen Event Considerations.

From a process safety standpoint, application of Kaizen would have focus on the reduction of residual risk (=waste) or activities that provide no/limited risk reduction. Commonly used team-based methods that achieve risk reduction include Process Hazards Analysis (PHAs) in its many forms, emergency preparedness reviews, Job Hazard Analysis (JHA), and inherently safer design reviews. While these may indeed be data driven systematic approaches for defining risk reductions, the teams usually have little incentive or charter to verify that that the recommended risk reduction measures actually achieved the desired result. The motivational aspect of Kaizen rarely manifests itself in these activities. The author can recall few HAZOP sessions that would qualify as “fun” with corresponding celebrations of success. A HAZOP team may disband without knowing if the team efforts paid off with demonstrated risk reduction and a safer plant, or for that matter, if any of the recommended changes were made at all!

Process Safety practitioners have recognized that the next wave of improvement to major accident hazard management lies in the behavioral aspects of workers and leaders. Building upon good standards and management practices, the behavioral aspect influences how individuals internalize and apply those practices willingly. Kaizen has long recognized that effective solutions have a factual/technical component and a personal component; it is the latter that seems to be in need of improvement in the process safety arena. Process Safety professionals have many approaches for analyzing the risk-improvements in a manufacturing plant; however, methods to imbed a process safety philosophy (a much softer, fuzzier, concept) in its employees are not nearly so common. The Kaizen model may be one such mechanism to fuse the process safety philosophy and risk management approach.

3. Poke yoke

Poke yoke (poh-kah yoh-kay) [4] is a Japanese term, and approach, for mistake proofing a design or process. Shiegeo Shingo (Toyota) is credited with first applying the term to the manufacturing industry. The basis for poke yoke is that defects occur because of worker errors. Therefore, to prevent errors, a mechanism needs to be in place to alert the worker to the potential for error and, where possible, eliminate the error early in the process thereby taking a preventive approach. Although poke yokes may be used for mistake proofing any process, poke yokes are usually targeted to repetitive tasks where the potential for human error is more likely. An example of poke yoke in everyday situations is the requirement to remove your ATM card before receiving cash-thereby reducing error and orphaned ATM cards. An example of poke yoke principles in industrial environments would be the variety of connectors and fittings for industrial gasses applicable only to certain gases. This prevents, for example, inadvertent connection of inert nitrogen to breathing air.

Central to application of poke yokes is the need to understand those tasks, activities, or functions that pose potential for human error. As with Kaizen, it is important to physically be where the work is being carried out and involve those who carry out the work. Process or task mapping of the work is important to systematically identify those opportunities for mistake proofing. In poke yokes, there is a preferred hierarchy for implementing solutions. Preference is given to those solutions that prevent potential for human error, rather than solutions that require recovery from human error. For example, a mistake-proof way to verify that a tank vent is open before de-inventorying an atmospheric tank is a better solution than methods alerting the operator that a "suck-in" is imminent. Additionally, there is to be a preference for the simple, inexpensive, solution over the complex. Data suggests that the majority of effective poke yoke devices or solutions cost less than $500 to implement.

Though mistake proofing can be built into design, some activities require checks by workers. Poke yokes promote conducting 'source' inspections to verify that conditions for safe/error-free execution of a task are in place prior to conducting the task. "Informative" activities are used during a task to provide feedback or a self-check that controls are in place. 'Judgment' inspections may be used to discard or halt work judged to be in error. These three inspections are given in preference order, and for critical processes, a combination of all three may be warranted.

As an example, if a company manufactured large batches of relief valves, "source" inspections by the line employees would be made to verify that raw materials had proper certificates, manufacturing processes were properly adjusted, and that test equipment has been calibrated. Once in the process of manufacture, "informative" activities (such as verifying correct assembly) may be conducted, providing another step to avoid manufacture of substandard valves. "Judgment" inspections in this case may include additional tests or checks if higher than usual failure rates are discovered, or, for example, if "equivalent" substitute parts were used-raising suspicion whether the product truly satisfied design requirements. A combination of these layered checks does not have huge cost implications, but can prevent batches of valves being rejected.

A similar approach may be used for hazardous activities; it is not limited to manufacturing processes. Where process plant operators have repetitive activities (such as changing filters, process sampling, minor maintenance, loading/unloading tank cars, etc.), poke yoke may be used to identify better approaches to the task-even for those individuals who have been doing those tasks for decades.

Successive checking is also called for to avoid having mistakes go unchecked; the sooner feedback is given, the sooner corrections may be made. This procedural approach to mistake proofing is evident in energy isolation procedures where all successive workers confirm that the system is indeed de-energized prior to conducting work.

Extensive treatment of human error in process safety is given in the book *Guidelines for Preventing Human Error in Process Safety* [5].

4. TRIZ (theory of inventive problem solving)

Process safety activities sometimes conflict with desired operational requirements. In process safety, there is an underlying drive to eliminate or minimize hazardous substances with a preference for simple solutions over complex ones. These principles are not always possible to achieve in light of production demands and chemical process design. Thus, as both process safety and process design practices have evolved, there is a constant struggle to achieve optimum business performance with safe operation. Reconciling these two sometimes opposing demands requires innovation and problem solving.[2]

Where long established solutions exist, these solutions tend to be codified in engineering and technical standards (e.g. improved pump designs, material properties and selection, corrosion protection methods). However, when the solutions are not obvious, or improvements on existing solutions are needed, one would not only desire to determine *what* needs improvement, but also consider alternatives of *how* to approach it. Often, the individuals tasked to resolve these technical issues have experience and knowledge in one or two fields of study, and may not be aware of possible solution alternatives. TRIZ [6] (pronounced *trees*) helps feed innovation by building on an empirical catalog of how technical innovation has occurred in the past. Process safety professionals encourage learning from events and accidents to avoid the same or similar event from recurring. Through TRIZ, inventive problem solving builds on the experience of thousands of previous problem solvers, and points one to solution areas worthy of consideration. It is usually applied to objects and much less so to processes, chemical or otherwise.

At its core, TRIZ is built from the concept of *ideality* which, simply put, is that technical systems must evolve toward elimination of harmful effects while leaving nothing but the beneficial effects of that technology—thus an ideal case.

Genrich S. Altshuller is regarded as the father of TRIZ. He was a patent expert in the former Soviet Union in the 1940's. As a mechanical engineer in this function, he began to see that very similar principles were used to solve problems as technology advanced. In fact, he determined that 90% of engineering problems posed had been solved somewhere else in very similar ways-the challenge was to guide the innovators to potential solutions that may be outside of their own experience base.

He initially screened over 200,000 patents looking for inventive problems and how they were solved (this was later increased to some 1.5 million patents world-wide). In this context, an *inventive problem* was one that introduced another problem, requiring resolution of both problems for the ideal solution. Rather than seeking a trade-off, he observed that the most inno-

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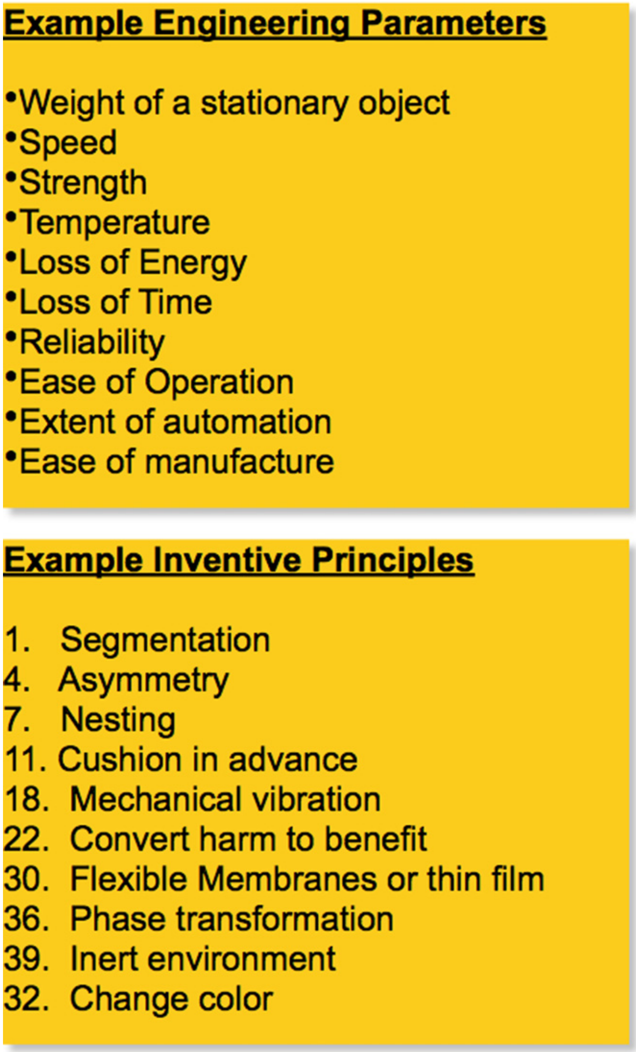
[2] The acronym TRIZ is the Russian acronym for "The Theory of Inventive Problem Solving".

vative solutions eliminated or resolved the contradiction. An example of this may be shown in modern LNG liquefaction plants where natural gas is processed and chilled to approximately −160 °C. Production demands require high throughput to produce the required volumes of liquefied natural gas, and a conventional gas ‘chilling’ heat exchanger design would be prohibitively large if construction was based on traditional design and materials. Several manufacturers were able to resolve the capacity and size/weight contradiction through innovative use of lighter, more heat conductive, aluminum components while simultaneously increasing the available surface area for more efficient heat transfer. Thus, the contradiction of throughput capacity and size was addressed.

Altshuller organized his observations and provided a way to connect the engineering parameters to the inventive principles. The basic components of the method are:

- *39 Engineering Parameters*. These fundamental 39 parameters were identified as features of inventive problems posed in patents. See Fig. 3 for examples.
- *40 Inventive Principles*. These 40 principles represent the various problem solutions that resolved contradictions.
- *Contradiction Matrix* [7]. This matrix, Fig. 4, is a road-map between the technical contradiction and the possible solutions given in the 40 inventive principles. The 39 Engineering parameters are present in both an x and y axis, giving a 39 × 39 matrix. The Contradiction Matrix is, in principle, applicable to all contradictions, regardless of the problem at hand. The ‘improving feature’ of the problem (e.g. improved reliability) is given on one axis, while the other axis represents ‘worsening features’ that may be secondary problems; thus a contradiction. At the intersection of each improving feature and worsening feature, applicable inventive principles are given by reference number.



Example Engineering Parameters

- Weight of a stationary object
- Speed
- Strength
- Temperature
- Loss of Energy
- Loss of Time
- Reliability
- Ease of Operation
- Extent of automation
- Ease of manufacture

Example Inventive Principles

1. Segmentation
4. Asymmetry
7. Nesting
11. Cushion in advance
18. Mechanical vibration
22. Convert harm to benefit
30. Flexible Membranes or thin film
36. Phase transformation
39. Inert environment
32. Change color

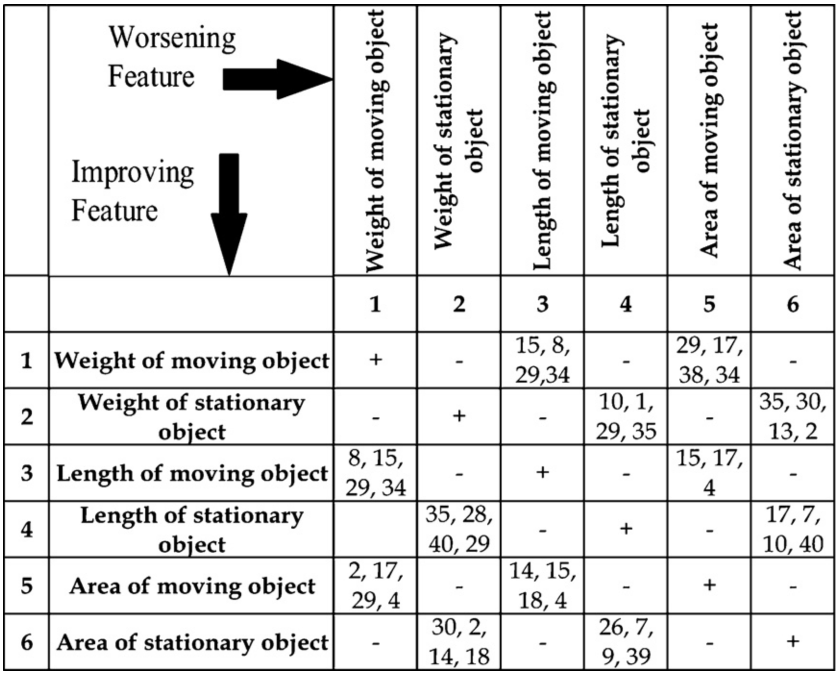
Fig. 3. Selected TRIZ Features.

Key to application of TRIZ is the following, Fig. 5:

- Capability to define a problem in technical terms, recognizing that resolution of one problem may introduce another (e.g. higher operating temperatures/pressures may increase production, but also may affect the potential for corrosion or cracking in pressure equipment).
- Once the problem is defined, technical attributes of the problem and the possible secondary effects are represented in terms of the 39 engineering parameters. This important step is crucial for successful TRIZ application. It requires some knowledge of cause and effect; some have suggested that Root Cause Analysis would be a very good tool to correctly mate the ‘improving’ feature to the ‘worsening’ feature.
- The contradictions table then provides a link to a selection of inventive principles (by number) that might be considered in the solution. By thoughtful consideration of the inventive principles shown, the ideal solution may be discovered.

Table 1
Inventive principles applied to sofa-balloon case

Inventive principle	Suggestion	Possible application to problem
#2 taking out	Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object	The necessary part of the sofa is the seat, to meet the owner’s desire. Build the balloon basket with one side in the shape of a sofa, thus adding no “new” mass to the structure
#13 the other way around	Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it)	Rather than putting a sofa in a balloon, put the balloon in the sofa. A giant sofa shaped balloon, or a sofa filled with lighter than air materials (e.g. inflatable)



	Worsening Feature → Improving Feature ↓	Weight of moving object	Weight of stationary object	Length of moving object	Length of stationary object	Area of moving object	Area of stationary object
		1	2	3	4	5	6
1	Weight of moving object	+	-	15, 8, 29,34	-	29, 17, 38, 34	-
2	Weight of stationary object	-	+	-	10, 1, 29, 35	-	35, 30, 13, 2
3	Length of moving object	8, 15, 29, 34	-	+	-	15, 17, 4	-
4	Length of stationary object		35, 28, 40, 29	-	+	-	17, 7, 10, 40
5	Area of moving object	2, 17, 29, 4	-	14, 15, 18, 4	-	+	-
6	Area of stationary object	-	30, 2, 14, 18	-	26, 7, 9, 39	-	+

Fig. 4. Excerpt of TRIZ Contradiction Table.

Consider this somewhat absurd, but thought provoking illustration: a somewhat eccentric hot air balloonist is weary of standing in the suspended basket, and wants to have a sofa to sit on. Such a luxury must be carried out in a way to avoid exceeding the load capacity of the balloon. In this case the "improving" feature is #33, Ease of Operation, with the worsening feature (the contradiction), #1 Weight of Moving Object. For this case, the contradiction matrix suggests several Inventive Principles that may apply (i.e. #25, #2, #13, and #15). For brevity, only a few of the Inventive Principles are given in Table 1 along with a suggested approach from the guidance of the Inventive Principles. The possible applications are spawned by an "extensive" 5 min brainstorm with the author's colleagues.

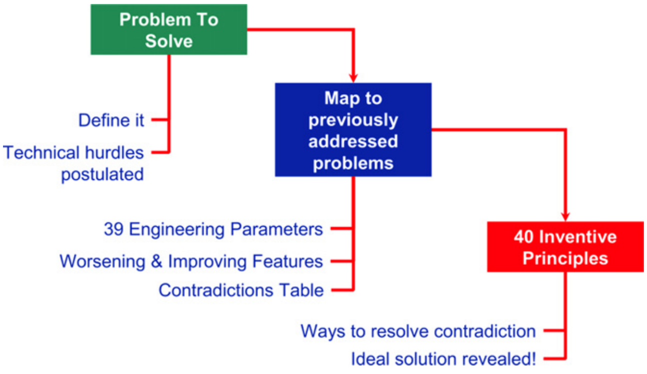


Fig. 5. TRIZ Process Summary.

Table 2
Examples of inventive principles and process safety measures [9]

Risk strategy	Example inventive principles[a]	Example process safety measures
Physical contradictions	(1) Separation/segmentation	Separate hazardous areas from populated areas
	(2) Taking out	Substitute a less hazardous component for a hazardous component
	(3) Local quality	Consider geological or weather effects in determining placement of process units
Technical contradictions	(4) Universality	Select components that fulfill multiple functions
	(5) "Nested doll"	Nested control loops
	(10) Preliminary action	Purging confined spaces of hazardous substances prior to entry. Energy isolation
	(27) Inexpensive, short-lived objects	Rupture disk
	(28) Mechanics substitution	Use a tracer gas for easier detection of leaks
	(29) Discarding/recovering	Select process with non-hazardous waste
	(35) Parameter changes	Transfer & handle substances in safer physical state
Organizational contradictions	(12) Equipotentiality	Design operator tasks to minimize fatigue (e.g. elevation changes)
	(15) Dynamics	Account for variability in operator and maintenance skill sets
	(17) Another dimension	Redesign operator interface to control panel
	(23) Feedback	Audits, reviews, key performance indicators

[a] Numbers reflect TRIZ Inventive Principle reference numbers from 1 to 40. A selection is given here.

Applying TRIZ for process safety “inventions” and innovation is likely to be for securing incremental improvements in process performance, or for combining two otherwise established solutions into a new innovation. Hazan [8] suggests that its application for safety parallels a risk mitigation strategy where gains are made through a layered approach to resolving contradictions:

- Inherent safety parameters are addressed through exploring *physical contradictions*. Following that,
- Engineered safety and safeguards are addressed through exploring *technical contradictions*, and
- Procedural/operations safety parameters are addressed by exploring *organizational contradictions*.

As with the balloon example, various solutions or measures may be taken to address the process safety contradictions. Table 2 provides process safety measures that may be associated with various TRIZ Inventive Principles.

The examples shown above are very general in nature, and provide an indication of the direction that maturing technology systems may be driven when applying TRIZ principles. As a recent example, there is an industry effort to radically re-design rail tank cars carrying hazardous materials. TRIZ is one of the methods being used to design an innovative tank car that is 5 to 10 times less likely to release cargo in accidents.

Although TRIZ was constructed with innovation, technology performance, and quality improvement in mind, there appears to be movement toward its use for improvement of safety and business processes.

5. Concluding remarks

The paper summarized three methods in common use in the field of quality and manufacturing process improvement. All methods have a technical basis, but rely on the human element for lasting effect. Practitioners of quality improvement are honing manufacturing processes to achieve defect-free processes, and a combination of quality control and quality management approaches are used to achieve success.

There is no silver-bullet for managing Process Safety. A variety of approaches working in concert, and continuously improved, will lead to safer operating plants. It is hoped that this brief exploration of manufacturing process improvement tools used to improve quality will foster equally effective improvements in the management of Process Safety.

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