IPO - Innovative Process Chain Optimization with TRIZ and TOC

Prof. Dr.-Ing. Dr. h.c. mult. Prof. h.c. mult. Tilo Pfeifer
Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen

Abstract
The competitiveness of modern-day companies is more than ever a direct function of their ability to implement process innovations and optimization. Such optimization, however, is becoming increasingly harder to realize, due to the growing complexity of the ways in which the networks of structures and processes in the manufacturing area are connected. The objective of this paper is to show a new systems approach for an innovative breakthrough of process chain improvements in manufacturing with TRIZ and TOC tools.

Challenges of Process Optimization in Manufacturing
In operational practice, process optimization often means trouble-shooting. People in charge of (continuously) improving production processes strive towards “problem solution in a single stroke”. The analysis of the problem frequently gets a raw deal. If any, primarily basic tools for problem solving (e.g. brainstorming) and trial-and-error are applied. The quality of the solution is strongly pending on the experience and intuition of the problem-solver. Furthermore, many great ideas fail in the implementation stage. When the complexity of the problem is high and no obvious solution is known this approach reaches its limits [1].

Quality management in manufacturing provides several tools to support optimization efforts. Failure Mode and Effect Analysis (FMEA), Statistical Process Control (SPC) or test data evaluation can be used to reveal problem areas in a process chain. Design of Experiments (DoE) is a powerful tool that helps to understand an individual process and to optimize it for all critical outputs. However, classical tools of the Quality Management for manufacturing are mainly focused on the prevention of failures without considering and questioning the existing structures as a whole. The efficiency and the effectiveness of a process chain are not only measures of defects but are multidimensional. This is where classical methods often run into their limits. Technologically mature systems – which serial production facilities invariably are – can only be improved on a profound level by integrated system analyses and holistic optimization efforts that may result in innovative process design. This means that a large part of the optimization potential in the production sector and neighboring fields remains untapped so far. A holistic approach for innovative process chain optimization is required. This approach needs to utilize classical and innovative methods that can cover the integrated analysis of the process chain, the systematical generation of innovative solutions and their safe implementation.

The Project »Innovative Process Chain Optimization«
The objective of the research project was to develop of a system which allows the holistic optimization of process chains in the manufacturing area with a view on increasing quality and performance. For practical purposes, a pertinent procedure was developed which successfully combines conventional quality management methods with new and integrated approaches. These incorporate the Theory of Inventive Problem Solving (TRIZ/TIPS) and the Theory of Constraints (TOC), which both provide high-performance tools for process optimization. The palpable results of the project include an advanced tool kit for quality management operations in manufacturing business environments. The contained tools support
In the optimization of a process chain, the project team has to face a problem which is usually characterized by many requirements and objectives, some of which are conflicting. This is called an inventive problem and may contain contradictory requirements. Knowledge and creativity are two essential conditions for a successful solution. However, there is often a lack of both [2].

Even though the composition of the team is interdisciplinary, it is virtually impossible to integrate universal knowledge of all specialized areas into a team. Independent studies have shown, that creativity diminishes steadily throughout the work phase of life [3]. Many people hesitate to be creative, because they fear that they lack the essential skills. In general, humans solve problems by analogical thinking (compare figure 1). We try to relate the problem we are facing to some standard problems (analogs) we are familiar with, and for which a known solution exists. If we can draw the right analogy, we can find the right solution. Our knowledge of such analogous problems, however, is the result of our educational, professional, and life experiences. Ideally, all potential directions for solutions should be equally regarded. In reality however, only solutions within one's own experience are considered while the consideration of alternative technologies to develop new concepts is ignored [4]. This results in what is called the “psychological inertia” which defeats randomness and leads only into those areas of personal experience.

For process optimization it would be a decisive advantage if the team has an extensive knowledge base and is capable of generating innovative concepts purposefully and systematically, rather than more or less at random. The TRIZ method provides some suitable tools. TRIZ expands the knowledge horizon of the developer by using a scientific-engineering knowledge base and supports the user systematically throughout the process of creative problem solving. The method ensures an effective and efficient search for innovative solutions, focusing on the so-called “Ideal Final Result”. It limits the search field considerably, but forces creativity within that search field. TRIZ also helps the user to detach himself from the psychological inertia vector, i.e. from his usual thought patterns and structures [5].

Figure 1: Generating Breakthrough Solutions with TRIZ

TOC - From Concept to Implementation

With the Theory of Constraints (TOC) another powerful methodology for process chain optimization was identified. TOC offers a lot of promising synergy to TRIZ. Both share the assumption that most core problems exist because some underlying conflict or contradiction prevents straightforward solution of a problem. Each approach is capable to analyze the problem situation and to identify the conflict. TRIZ is especially strong in generating innovative concepts to overcome these conflicts. TOC additionally provides tools to answer the question »How do we implement this change?«.

The Theory of Constraints is a systematic approach to continuous improvement that has its basis in the manufacturing environment. TOC was developed by Eliyahu M. Goldratt in 1984 which he presented in his first book ‘The Goal’. Goldratt likens (production) systems as chains, or networks of chains. A process chain in manufacturing can be thought of as a chain of dependent events that are linked together. The activities that go on in one “link” are pending upon the activities that occur in the preceding "link". Since »a chain is only as strong as its weakest link«, optimization efforts should focus on "chain strength" by working to strengthen the weakest link – the constraint. TOC is based on several principles
that are very important for successful improvement. The crucial principle is»Systems as Chains« that has already been
mentioned[6]. Other vital ones are:
»Cause and Effect «: All systems operate in an environment of cause and effect. One particular event acts as a cause for
another event, while the particular cause leads to a specific effect. This relationship between cause and effect can be very
complex.
»Undesirable Effects and Core Problems«: The indication of the existence of a problem is brought out by undesirable
effects (symptoms). Eliminating undesirable effects gives a false sense of security. The elimination of the core problem,
however, not only eliminates the symptoms but prevents them from happening again.
»Solution Deterioration«: The solution to any problem deteriorates with time, because the environment changes. Hence,
a process of continuous improvement is required to maintain the same levels of efficiency at all times.
»Ideas are not Solutions«: Mere the idea on how to solve a problem does not result in improvement, rather, the effective
implementation of this idea that results in real improvement. However, in many cases ideas fail in their implementation
stage.

The TOC thinking process focuses on the answer to three fundamental questions: »What to change?«, »What to change
to?« and »How to cause the change?«. This process is supported by specific tools, the five logical trees. The Current Reality
Tree (CRT) is designed to analyze the current condition of a system and to gain a better understanding for the problem.
It identifies the core problem(s) that lead(s) to observed undesired effects which decrease(s) the performance of the
system. Solving these core problems becomes the objective. This often requires the elimination of an underlying conflict, that
prevents straightforward solution. The Conflict Resolution Diagram (CRD), also referred to as “Evaporating Cloud”, helps
to resolve these conflicts and strives to create a breakthrough solution to the problem that avoids compromise. Being
armed with the tools of TRIZ is here particularly useful. Once a proper improvement measure has been found, the Future
Reality Tree (FRT) serves to check if it will in fact produce the desired effect without introducing new and unexpected
side effects. The FRT can also effectively test alternative solutions before allocating expensive resources to them.

Once the realization of an appropriate solution has become the objective the Prerequisite Tree (PT) comes into operation.
The PT is designed to find all obstacles and the responses needed to overcome them in realizing the objective. It identifies
minimum necessary conditions and requirements without the objective cannot be achieved. The result of the PT is a se-
quence of intermediate objectives to be followed in order to neutralize all obstacles. The TOC thinking process is com-
pleted by the Transition Tree (TT). The TT provides a detailed step-by-step instruction for implementing a course of ac-
tion. It shows all the steps necessary in achieving a specific objective, providing a so called ‘road map’ to the entire im-
plementation effort. The construction and review of the trees is governed by so-called Categories of Legitimate Reserva-
tion (CLR). These are eight rules, or tests of logic, that are applied for building, scrutinizing and improving the trees. They
also serve to communicate effectively disagreements related to the construction of relationships. The CLRs are clarity,
entity existence, causality existence, cause sufficiency, additional cause, cause-effect reversal, predicted effect existence
and tautology[5].

Both approaches, TRIZ and TOC, provide tools for analyzing the initial situation and for identifying core problems. TRIZ
is extremely powerful in generating innovative solutions that overcome underlying conflicts/contradictions and bring the
system closer to ideality. The solutions found with TRIZ can be successfully scrutinized and implemented by applying the
last three tools of the TOC thinking process (FRT, PT and TT). The combined use of classical QM-tools, TRIZ and TOC
promises a holistic optimization of process chains in manufacturing, without giving in to compromise. However, to
achieve this, two steps are essential. On the one hand some of the individual tools are to be redesigned in order to fit them
together. On the other hand a procedure is developed that sets the individual tools into a context.

DMAIC – Step-by-Step to Success

The system for innovative process chain optimization that was developed in the research project consists of two major
elements. A procedure describing the course of an optimization project and an interdisciplinary toolset that supports each
stage of the model. The toolset contains TRIZ-, TOC- as well as classical QM-tools. The procedure was developed on the
basis of the DMAIC cycle (Define-Measure-Analyze-Improve-Control) that originates from the Six Sigma approach
(compare figure 2)[7].

In the Define-Phase the team has to identify and define the problem, the objective, customer requirements (internal and
external) and important boundary conditions. The process chain to be investigated needs to be understood. To support this
stage the Define-Checklist was developed, based on the Innovative Situation Questionnaire of TRIZ.

The objective of the Measure-Phase is to determine the current performance of the process and the extent of the problem.
The current state of the process is recorded which is essential to rate the achieved success at the end of the optimization
project. The Measure phase also prepares the analyze step of the DMAIC cycle by gathering key data that helps to identify
the process constraint. Usually a lot of data (test data, MTM, …) is already available in the manufacturing area.
The gathered data is scrutinized in the Analyze-Phase. This stage can be classified into data analysis and process analysis.
The common objective is to identify the root causes of the problem and the constraint. As a result of Analyze, optimiza-
tion priorities are set up. Classical QM-tools (Capability studies, 7 tools, …) may serve for data acquisition and evaluation. The process analysis can be effectively supported by the CRT.

The optimization problem is solved in the Improve-Phase. The constraint in the process chain is examined carefully in order to find out how to elevate it. Sub-problems, conflicts and/or contradictions are systematically revealed by applying several powerful TRIZ-based tools (e.g. Function-Effect-Modeling). Innovative concepts for solutions are generated, structured and compared. The solutions to be implemented are selected. This can be done by portfolio analysis (e.g. chance/risk; cost/time) or the application of the Future Reality Tree, for instance. The implementation of these solution is methodically safeguarded by the Prerequisite Tree and Transition Tree. The first 4 steps of the DMAIC cycle were dedicated to identifying, measuring and implementing change. However, without sustaining the gain, the initial enthusiasm for improvement can easily be lost.

The Control-Phase serves for confirming the fact that the improvement measures selected have achieved the goal set up in Define. Therefore, compiled result data has to be reviewed. A second important objective of Control is to select ongoing measures to monitor performance of the process and continued effectiveness of the implemented solutions.

Figure 2: Overview over the five phases of the IPO Systematic

Conclusion

Classical methods of quality management in manufacturing already do a good job in the prevention of failures and can optimize the output of an individual process. However, improvement efforts normally focus on individual elements of a process chain and do not question the existing structures. When it comes to improving a process chain with a holistic view to increasing efficiency and effectiveness, the conventional QM-methods often reach their limits. Especially, when the complexity of the system is high, support is needed.

Core problems that prevent straightforward solutions are often caused by an underlying conflict or contradiction. For example, from the current point of view, improving one characteristic of the process will result in impairing another characteristic. Hence, a trade-off seems to be necessary. TRIZ provides powerful tools for overcoming conflicts and contradictions without the need for compromise. TRIZ expands the knowledge horizon by providing a knowledge basis that represents the combined experience of over 2.5 million patents. It also helps users to detach themselves from their usual thought patterns and structures.

Armed with TRIZ, the optimization team can generate innovative concepts for breakthrough solutions. However, ideas or concepts are no solutions. Not until they have been successfully implemented. The implementation stage needs to be methodically safeguarded as well. This is where TRIZ and TOC can complement each other. TOC provides tools that enable the user to evaluate alternative concepts for solutions and ensure successful realization. TOC also supports the analysis of the process chain in order to identify the “weakest link”, the constraint, that needs to be strengthened.

The DMAIC cycle as a proven procedure for process optimization sets the individual tools into context. It emphasizes the measurement of the current performance of the process chain, which is essential to evaluate the achieved improvement. The concerted application of classical QM-tools, TRIZ and TOC in the DMAIC cycle results in a holistic optimization of process chains with innovative design. Even if the maturity of the system is high, improvements in quantum leaps are possible. The system for innovative process chain optimization enables enterprises to tap substantial innovation-based optimization potentials and contributes to improving both their quality standards and their competitiveness.

Literature


Biography

Prof. em. Dr.-Ing. Dr. h.c. mult. Prof. h.c. Tilo Pfeifer, born in 1939, graduated from the Aachen University of Technology (Rheinisch-Westfälische Technische Hochschule, RWTH) with a degree in Electrical Engineering. Since 1972, he has been working as Professor at the Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen. Moreover he is Head of the Department of Metrology and Quality Management at WZL, and the Department of Metrology and Quality Management at the Fraunhofer Institute of Production Technology (IPT).