Systematic innovation and the underlying principles behind TRIZ and TOC

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Abstract

Innovative developments in the design of product and manufacturing systems are often marked by simplicity, at least in retrospect, that has previously been shrouded by restrictive mental models or limited knowledge transfer. These innovative developments are often associated with the breaking of long established trade-off compromises, as in the paradigm shift associated with JIT & TQM, or the resolution of design contradictions, as in the case of the dual cyclone vacuum cleaner. The rate of change in technology and the commercial environment suggests the opportunity for innovative developments is accelerating, but what systematic support is there to guide this innovation process. This paper brings together two parallel, but independent theories on inventive problem solving; one in mechanical engineering, namely the Russian Theory of Inventive Problem Solving (TRIZ) and the other originating in manufacturing management as the Theory of Constraints (TOC). The term systematic innovation is used to describe the use of common underlying principles within these two approaches. The paper focuses on the significance of trade-off contradictions to innovation in these two fields and explores their relationship with manufacturing strategy development.

Keywords: Systematic innovation; TRIZ; TOC; Constraints management; Trade-offs; Manufacturing strategy

1. Introduction

The concept of trade-offs, or conflicting performance parameters is a central feature of mechanical design where speed and efficiency, or strength and weight performance conflicts are readily acknowledged. These are typically well documented and the performance trade-offs are balanced in the design process to give the optimum for a particular application. What is less well known is the significance of these contradictions in the innovation process. The practice of using trade-off parameters as a focus for systematic innovation in mechanical design has only recently emerged from Russia under the name of TRIZ (The Theory of Inventive Problem Solving), but it is already attracting significant industrial interest [1].

In the field of manufacturing it is over 30 years since Skinner [2] used the concept of mechanical design trade-offs to help acknowledge and manage conflicting performance parameters associated with manufacturing. This extract from his seminal work illustrates the mechanical analogy.

'For instance, no one today can design a 500 passenger plane that can land on a carrier and also break the sound barrier. Much the same is true of manufacturing. The variables of cost, time, technological constraints, and customer satisfaction place limits on what management can do, force compromises, and demand an explicit recognition of a multitude of trade-offs and choices.' [2]

From this and subsequent papers the strategic trade-offs associated with manufacturing investment and decision-making became explicitly recognised. The term 'manufacturing strategy' emerged with a new awareness of performance conflicts and the need to make strategic choices between competitive criteria, such as speed and efficiency, or quality and cost. Since then the debate has moved on and some of the originally cited trade-offs are acknowledged to have been all but eliminated in certain sectors, with the application of developments such as JIT and TQM, now often cited as heralding a new manufacturing paradigm [3]. As a consequence some would argue the trade-off analogy with mechanical design is no longer relevant [4]. Others argue that trade-offs change [5-7], as with mechanical systems, but the perceived role of the trade-off concept is largely limited to one of acknowledging their existence, so that the negative impact can be minimized.

This paper aims to shed new light on this debate by exploring the deeper significance of trade-offs in mechanical design before linking the analogy to organizational improvement and innovative developments in manufacturing. The thesis of this paper is that the concept of performance contradictions has much more to offer than has been widely acknowledged to date, not only in the design of artifacts but also manufacturing strategy. The paper will outline the TRIZ and TOC perspectives on performance contradictions, demonstrating the common underlying principles, before exploring the broader significance of trade-offs in manufacturing.

2. TRIZ

Work on TRIZ, a Russian acronym for The Theory of Inventive Problem Solving, began in 1946 when Genrich Altshuller, a mechanical engineer, began to study patents in the Russian Navy. Over subsequent years his desire to structure the inventive process resulted in a range of tools and approaches based on empirical analysis. TRIZ has now been the subject of many person years of development and seen the study of over a million successful patents [8]. The approach has been widely taught in Russia, but did not emerge in the West until the late 1980s. The different solution systems have been derived by abstracting inventive principles from the ongoing analysis of patent data. Several of these focus on contradictions or trade-offs in identifying innovative solutions.

The TRIZ methodology claims that, *'Inventive problems can be codified, classified and solved methodically, just like other engineering problems'*. [9]

There are three premises on which the theory may be viewed:

- The ideal design with no harmful functions is a goal.
- An inventive solution involves wholly or partially eliminating a contradiction.
- The inventive process can be structured.

Each of these premises will be dealt with in turn.

2.1. The ideal design with no harmful functions is a goal.

Finding the ideal solution to a needed effect or function with no additional resources or negative secondary effects is referred to in TRIZ circles as Ideality.

$$\text{Ideality} = \frac{\text{All useful effects or functions}}{\text{All harmful effects or functions}}$$

The ideal being, to achieve all useful effects or functions with no harmful effects or, ideally, any use of resource. One can argue there is little new in this, as a similar emphasis on improving functionality is also evident in widely established approaches such as Value Engineering. However, the difference is that this thinking is central to TRIZ and specialist supporting tools have been developed that specifically concentrate on improving the functionality through innovation rather than the traditional cost cutting or sub optimisation focus.

2.2. An inventive solution involves wholly or partially eliminating a contradiction.

Altshuller's [10] early work on patents resulted in him classifying inventive solutions into five levels, ranging from trivial to new scientific breakthroughs. Through this work he defined an inventive problem as one containing at least one contradiction and that an inventive solution wholly or partially eliminated the contradiction. Altshuller claimed his solution systems could assist innovation at levels 2-4.

2.3. The inventive process can be structured.

This early work convinced Altshuller that there was potential to structure the inventive process around trade-off contradictions and it led to several developments, only two of which are introduced here. In each case empirical data was used to develop correlation operators using the principle of abstraction. Figure 1, illustrates this abstraction process, which classifies problems and solutions in seeking correlation that enables a set of generic problem solving operators or principles to be identified. This basic model will be referred to as we look at two solution systems of classical TRIZ base around contradictions.

2.3.1. Technical Contradiction Solution System

After having identified the significance of contradictions Altshuller went on to classify them into 39 parameters and in a similar way he identified 40 common principles that he found had been repeatedly used in patented solutions. To display the possible technical contradiction combinations he produced a 39x39 matrix and identified which of the 40 inventive principles were more commonly associated with specific combinations of contradiction parameters. This matrix is called the Technical Contradiction Matrix.

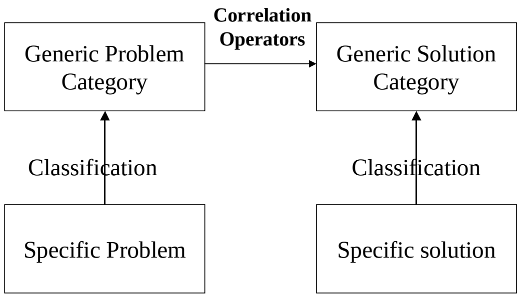

Figure 1: The general case for abstracting a solution system.

By way of illustration, if we consider Skinner's aircraft example, a typical trade-off might be speed versus adaptability (e.g. take-off and landing distances). The above TRIZ approach to breaking this contradiction would be to relate the trade-off parameters to the 39 standard technical contradiction parameters to find the closest match. In this case there is an exact match Speed (parameter 9) and Adaptability (parameter 35). The Contradiction Matrix developed by Altshuller recommends 3 of the 40 principles (principles 15, 10 & 26) for early consideration. Principle 15 is 'dynamicity', which is illustrated with various examples that can be linked to the concept of variable wing geometry as a possible solution. This could have classified as a level 3 solution.

These 40 inventive principles and the Contradiction Matrix have stood the test of time, however this was only the first of the TRIZ solutions systems.

2.3.2. Physical Contradiction Solution System

Over a period of time Altshuller et al. identified a further level of abstraction from the technical contradictions. He found that in many cases the technical contradiction could be presented as two extremes of one feature, which he called a physical contradiction. Put more formally: A physical contradiction requires mutually exclusive states as they relate to a function, performance or a component. Typical physical contradictions include: fast vs. slow; solid vs. porous; moveable vs. stationary; hot vs. cold; etc.

The relationship between the technical and physical contradictions has been graphically illustrated , as shown in Figure 2. In the figure, a technical contradiction between parameters A & B has been further abstracted to present the contradiction in terms of a common variable parameter C, which represents the physical contradiction. Altshuller found that by defining the contradiction around one parameter with mutually exclusive states the correlation operators used to detect a solution could be more generic and there are just four separation principles used to help resolve this type of contradiction.

These separation principles can be summarised as:

Separation of opposite requirements in space;

Separation of opposite requirements in time;

Separation within a whole and its parts;

Separation upon condition.

Figure 3 illustrates the relationship between these two levels of

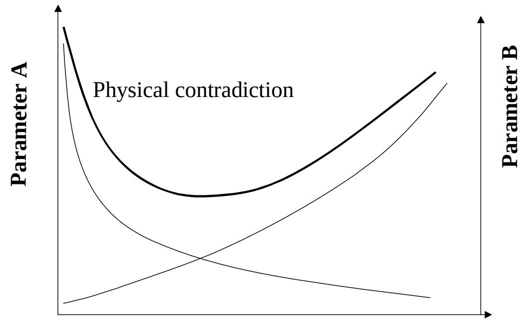

Figure 2: A graphical illustration of a physical contradiction

abstraction. If we consider the aircraft example again, this further level of abstraction would take the original technical contradictions of speed and adaptability and look for another common parameter displaying mutually exclusive states, as displayed in figure 2. Such a parameter in this example might be wing area. For speed a small wing area is required, but for take-off, landing and general manoeuvrability a larger wing area is required. The four separation principles would then be considered and in this case 'separation in time' naturally leads to the possible

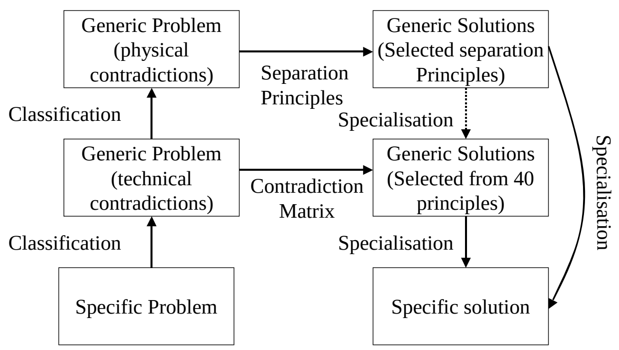

Figure 3 :The first and second levels of abstraction

option of variable wing geometry.

2.4. Conclusion

These two solution systems represent the founding work of TRIZ centred on contradictions. For a more comprehensive introduction see [8,9] or for more detail see [11]. Having introduced the innovative role of trade-offs in mechanical design let us now look at the related aspects of the TOC and distil out some of the common principles with manufacturing examples.

3. TOC

The Theory of Constraints (TOC) has been developing over more than 20 years by Dr. E Goldratt and from 1986 within the Avraham Y. Goldratt Institute (AGI), an educational institute for the development and dissemination of knowledge on the TOC. There are also independent user groups actively involved in the work, the most notable of which is the America Production & Inventory Control Society (APICS) Constraints Management Special Interest Group. [12]

TOC as with TRIZ is also focused on developing innovative solutions, but in this case the focus is on managing or breaking constraints within organisations. Since the mid 1980s the principles have been applied to addressing not only physical resource constraints, but also policy and paradigm constraints within organizations, which are often characterized as trade-off contradictions. A recent application of this work to conflicts associated with project management has resulted in the development of Critical Chain Project Management, now widely acknowledged by industry [13]. In addition to the development of these generic solutions there has been the parallel activity of developing a practical thinking process with associated tools [14], to which Goldratt attributes his generic solutions. This process centres on identifying and eliminating policy or paradigm constraints. There are two basic tools used in this process, one is used to map cognition through Effect-Cause-Effect (ECE) analysis, and the other is used to expose and break the core conflict or constraint through the use of the Evaporating Clouds (EvC) technique. As with TRIZ, TOC is very much industry led, but the theoretical basis is evident in more than just the title [15].

The underlying premises behind TOC may be viewed as:

- All organisations have a purpose or goal they aspire to continually move towards.
- Opportunity for purposeful value-adding improvement is limited by few constraints.
- Identifying and breaking these constraints can be structured.

Again, each of these premises will be dealt with in turn.

3.1. All organisations have a purpose or goal they aspire to continually move towards.

As TRIZ focuses on improving the functionality with minimum waste, TOC focuses on improving the value adding performance of the organization with minimal increase in cost. Where the organisation is for-profit the term Throughput (T) is used to identify the financial value added component, and Operating Expense (OE) is used to cover all other expenses. Therefore:

Value Added Productivity = T/OE

As with the Ideality ratio of TRIZ the statement is not original, but the focus together with the support tools is. TOC centres on increasing Throughput rather than reducing Operating Expense; arguing that although cost cutting is important it is limited and can be dangerous without a strategic perspective. Focusing on increased Throughput is inevitably strategic in nature requiring a systems view of the business to enable the identity of what limits or constrains current and future Throughput.

This focus on 'goal units' is also widely applied to non-profit making organisations, but the unit of measure is not so convenient in these cases.

3.2. Opportunity for purposeful value-adding improvement is limited by few constraints.

The TOC defines a constraint as, *'Anything that prevents the organisation from achieving higher performance versus its goal'*. So, in the case of a profit-making organisation this centres on what limits T. The TOC claim is that there are few constraints to any system preventing it from achieving its goal.

Although TOC originally focused on physical resource constraints the underlying constraints are commonly policy, or deeper paradigm constraints. TOC uses cognitive mapping to verify this assumption where necessary, but there are many other authors who acknowledge the importance of underlying core problems that constrain system improvement.

As with TRIZ these constraining core problems are exposed as contradicting requirements that otherwise tend to be ignored or accommodated via local sub-optimisation models.

A classic example of this is evident in the Economic Batch Quantity (EBQ) formula, graphically illustrated in figure 4. As can be seen the traditional batching policy represented by this simple model reflects the conflicting parameters in a similar way to the physical contradictions of TRIZ. This is a classic example of a trade-off compromise, viewed very narrowly with many embedded assumptions, which has proved to be increasingly invalid. However, such models represented a paradigm that has had wide implications in manufacturing management and there is a similar model for quality costs. JIT and TQM developments challenged the validity of such models in the 1980s, resulting in a paradigm shift in manufacturing management thinking.

It is clearly evident that the TRIZ concept of Physical Contradictions is closely related, and this will be illustrated later.

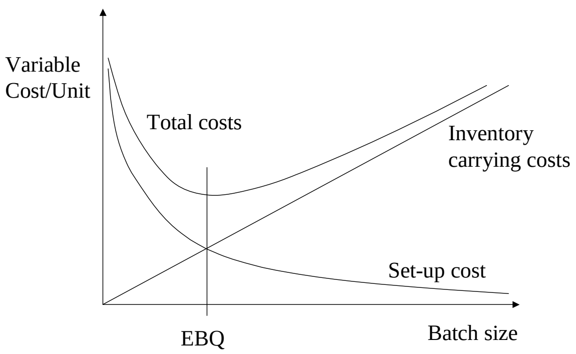

Figure 4 Traditional Batch Size Conflict

3.3. Identifying and breaking these constraints can be structured.

TOC and TRIZ actively seek out such compromises with a view to focusing attention on a critical area of the system and so enabling overall systems improvement. Typically the contradiction, or conflict of major concern, would be verified by a form of cause and effect analysis in both TOC and TRIZ [16].

In TOC the contradiction is presented in what is called an Evaporating Cloud (EvC), sometimes known as a Conflict Resolution Diagram. This cloud is a simplified cause and effect diagram used to expose and challenge the underlying logic linking conflicting needs. The cloud depicting the batch size conflict is illustrated in figure 5.

In the diagram, the requirements B and C are necessary (but not sufficient) to achieve the objective A. Similarly the prerequisites at D and D' are necessary (but not sufficient) to achieve the requirements at B and C, respectively. It is normal with the EvC to formulate the problem from the prerequisite conflict and to then work from there, clarifying the thinking

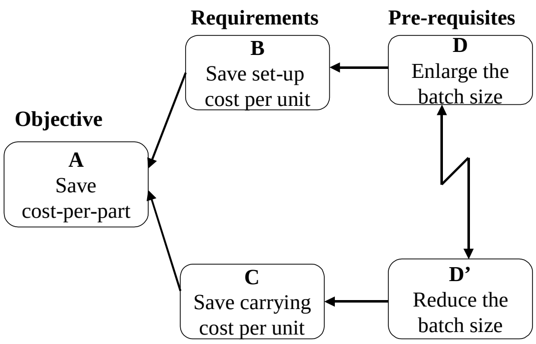

Figure 5 Batch Size Cloud

behind the causal links along the way, through B, C and finally A. This is however, usually an iterative process.

Each of the arrows in the diagram is then scrutinised during an analysis of the problem situation to examine the assumptions contained in the problem definition. In TOC terms, the Cloud is evaporated (i.e. the problem is solved) if one of the assumptions embedied in an arrow can in some way be invalidated. By way of example, both JIT and TOC have challenged the assumptions underpinning the arrow B-D, which states that large batches are a prerequisite for reducing set-up costs.

The JIT approach to this problem was to challenge the assumption that set-up times were immutable. The wider benefits of low inventory and the opportunity to simply reduce set-up time was a revelation to many industrialists and, in some cases, effectively eliminated the conflict at source with little expense.

The traditional TOC challenge to this arrow relates to the underlying performance measurement systems that assume that increasing the number of set-ups automatically means increased Operating Expense or reduced Throughput. In reality there is often spare capacity, which invalidates this assumption. But, more importantly, the impact on T & OE needs to be clearly distinguished and located if appropriate action is to follow, but more in this later.

This particular cloud has also been broken at the D-D' conflict arrow. The false assumption is that there is only one definition of 'batch', but the two requirements put different interpretations on the word. The conflict can be evaporated, at least in some cases, by acknowledging the distinction between a process batch and a transfer batch.

As we have already seen the breaking of the arrow at D-D' is closely related to the breaking of a TRIZ physical contradiction using the four separation principles. If we apply the principle of 'separate in time' the opportunity to distinguish between process and transfer batches becomes evident. Earlier work by the authors [16] has explored these parallels more closely.

3.3.1 The breaking of paradigm constraints

The breaking of clouds at arrow B-D or C-D' typically represents the breaking of a policy constraint, but the work of JIT, TQM and TOC went further than this. It can be argued that the batch size cloud is built around a 'costing paradigm' particularly prevalent in the West and graphically illustrated by Skinner in The Productivity Paradox [17]. Here, Skinner's casework illustrates how many American companies in the 1980s were focusing on a very narrow and declining perception of productivity and not considering the impact of their direct labour cost focus on the loss of orders through the trade-off with service and quality.

If we consider the evaporating cloud structure, the breaking of a paradigm constraint will tend to be at a more fundamental location, such as arrows A-B or A-C. In the case of this cloud the

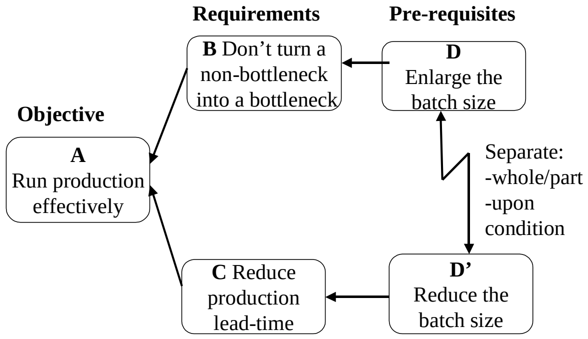

Figure 6 Batch Size Cloud in the 'Throughput World'
Source: [18] modified

objective is also embedded in the costing paradigm, which Goldratt refers to as the 'cost world' [18].

Having challenged the underlying assumptions Figure 6 is the revised version of the cloud, which redefines the objective and requirements. Requirement C now more clearly reflects the impact on customer service and therefore future Throughput, whilst requirement B reflects the need to consider available capacity and therefore the possibility of constraining current Throughput. This redraw of the cloud reflects the paradigm shift associated with TQM, JIT and manufacturing strategy thinking, but still leaves the same pre-requisite conflict. However, with the clarified requirements it makes it clearer how the contradiction may be separated out, as reflected in the Drum-Buffer-Rope approach to planning and control [19].

The TOC argument is that there are many possible improvements, but very few that will impact on what constrains Throughput. The cloud is used to acknowledge such conflicts and expose simple inventive solutions. Over the years, generic solutions have been developed, such as Drum-Buffer-Rope and more recently the Critical Chain [20] mentioned earlier. But even if these generic applications are relevant it is argued that the cloud still has its place in focusing attention and involving all relevant functions in gaining consensus and actively participating in developing tailored solutions.

4. Manufacturing Strategy

Having explored the deeper significance of trade-offs through TRIZ and TOC, let us consider the broader implication for manufacturing.

4.1. A way of thinking

Manufacturing strategy is often referred to as requiring a different way of thinking, which embodies a cross-functional perspective focusing on how the manufacturing function can support competition in the market place [6]. In a similar way TRIZ and TOC are concerned with a holistic thinking process, which incorporates a systematic means of focusing on customer centred value-adding improvements.

4.2. Acknowledge conflicting performance criteria

Skinner [2] and subsequently Hill [21] have stressed the need for manufacturing strategy development to start with the market, acknowledging that price is not the only competitive criteria and that satisfying different order winners and qualifiers requires different system designs with corresponding profiles. This is clearly evident in skinner's mechanical design analogy where aircraft design involves choices that acknowledge different customer requirements. The work of TRIZ has enabled the mechanical analogy to be taken further, as it identifies the relationship between innovation, the resolution of trade-offs and the emergence of new trade-offs at higher levels of performance. In a similar way strategic improvement of a manufacturing system can be allied to an ongoing process of resolving conflicts. TOC thinking also highlights the role of conflicts in this on-going innovation cycle. As the trade-off between conformance quality and cost has been resolved, other trade-off conflicts emerge that limit value adding improvement. In this way manufacturing strategy can be considered to focus on identifying and reconciling Throughput limiting trade-offs on an ongoing basis.

4.3. Reconciling the conflicts

Although TRIZ and TOC offer a common means of explicitly defining a conflict, there are clear distinctions in how they approach its resolution; whereas TRIZ tackles the contradiction directly, TOC challenges the origin of the perceived conflict.

The classic approach to resolving manufacturing trade-offs has been via Skinner's [22] focus factory concept, now widely adopted in industry. The TRIZ separation principles closely reflect the well-established hybrid focusing options [21], but the principles are also clearly evident in recently developed supply chain concepts, as in the case of postponement [23].

Trade-offs are also resolved through focused technical breakthroughs [24], where investment enables a performance trade-off to be alleviated. Although not specifically addressed here, such technical developments are central to TRIZ solution systems.

The JIT/TQM paradigm shift is clearly associated with resolving trade-off conflicts at a fundamental level. The resulting simpler systems demonstrate that these trade-offs effectively evaporate with the exposure of the false assumptions embedded in outdated management models. The TOC has been shown to provide a simple but effective approach to systematically challenging perceptions and assumptions behind such conflicts.

An illustration of the combined use of these approaches is evident in the supply chain conflict illustrated in figure 7. This cloud relates to a case [25] where the decision to outsource fashion sportswear manufacture from the USA to Honduras reduced the cost of manufacture, but had a detrimental effect on critical market response. The conflict was eventually resolved by separating out the requirements in time and space. Honduras providing the low cost early supply, whilst Griffin completes the order once sales demand at the start of the sales season has been determined. The use of technology to capture data at source supports the need to minimizing supply chain induced demand uncertainty. This case illustrates a common outsourcing dilemma and demonstrates the importance of understanding the strategic trade-offs associated with such global supply decisions, before challenging the thinking behind the conflict in tailoring win-win solution.

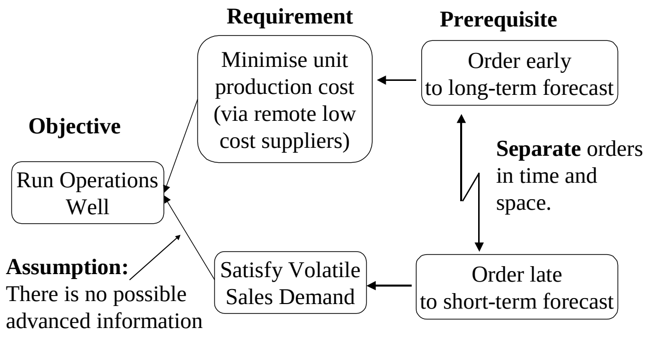

Figure 7 Global supply cloud

5. Conclusion

Common aspects and distinctions of TOC and TRIZ

- Both subordinate the importance of reducing cost in improving 'Ideality' and 'Value added productivity'.
- Both consider trade-off situations, in the form of conflicts and contradictions, as key to purpose focused improvement.
- Both claim that the resolution of contradictions and conflicts can be structured.
- The TRIZ concept of physical contradictions and the TOC evaporating clouds both center on explicitly defined contradictions and the EvC diagram provides a means of practical integration.
- Whereas the TRIZ solution systems apply principles to break the contradiction directly the TOC approach focuses on challenging the mental models underpinning the perceived conflict.

The term systematic innovation has been used to convey the common underlying principles embedded in these two industry based approaches to focused improvement. Both approaches view the identification and resolution of performance contradictions as key to the long-term value added improvement of a system and the tools used to break the conflict have been shown to be highly complementary.

The trade-off analogy associated with manufacturing strategy is still valid, but needs to be conceptually developed to encompass the importance of not only acknowledging trade-offs in managing the inherent conflict, but using the conflict as a focus for innovation. It is suggested that the systematic innovation concepts and tools embedded in TRIZ and TOC enhance the traditional manufacturing strategy thinking and the EvC diagram can be used to practically integrate their use.

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