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TQM, TPM, TOC, Lean and Six Sigma – Evolution of manufacturing methodologies under the paradigm shift from Taylorism/Fordism to Toyotism?

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Abstract

The evolution of manufacturing methodologies is explored based on a historic analysis of the automobile industry. The objective of this paper is to contribute to a clearer understanding of the evolution of these manufacturing methodologies.
The inherent historic driver and social needs are presented and the existence of a 'paradigm shift' from Fordism to Toyotism is discussed. The authors believe that sustainability and its inherent axiom of gentle and prudent usage of our remaining resources as the dominant constraint will coin the future role of operations research and management.

Keywords: Paradigm, Lean Production, Theory of Constraints

Introduction

Research Objectives

The main objective of this paper is to contribute to a better understanding of how manufacturing methodologies have evolved and to determine their differences and similarities. Based on this better understanding of the evolution the authors want to identify current and future needs that will lead to new or amended manufacturing methodologies.

Paradigms, methodologies, and techniques

Mingers and Brocklesby suggest that the world of research is separated into four levels, (1) paradigms, (2) methodologies, (3) techniques, and (4) tools (Mingers and Brocklesby, 1997). Kuhn defines a paradigm as "an entire constellation of beliefs, values and techniques, and so on, shared by the members of a given community" (Kuhn, 1996). Therefore for the purpose of this paper a manufacturing paradigm can be understood as the (maybe inherent) business assumptions that led to the characteristics and nature of current known manufacturing methodologies.

If we go down a level in perspective, within a certain paradigm a specific set of methodologies can develop and will therefore embody the philosophical assumptions of that paradigm. A methodology is a structured set of guidelines or activities to assist people in undertaking research or intervention (Mingers and Brocklesby, 1997). A methodology is also viewed as the principles of method (Checkland, 1999). Just as a paradigm can have a set of methodologies, each methodology in turn can be decomposed down to a set of techniques. A technique is a specific activity with a clear and well-defined purpose (Mingers and Brocklesby, 1997).
In this paper Total Quality Control (TQC), Total Quality Management (TQM), Theory of Constraints (TOC), Six Sigma and Lean Production are placed in the category of methodologies as they share or differ in underlying business assumptions and consist in general of a structure of guidelines and of techniques.

Definition of methodologies

Total Quality Control and Total Quality Management
Feigenbaum illustrates that Total Quality Management is the consequent further development of Statistical Process Control and Total Quality Control (Feigenbaum, 1991) (see Figure 1). The method of improving the quality by extracting faulty components became more cost-effective with the introduction of statistical measures which can mainly be traced back to Shewart who introduced the difference between chance-cause and assignable-cause origins of variations and developed the quality control chart (Shewhart, 1980).
TQM is defined by Feigenbaum as both a philosophy and a set of guiding principles that represent the foundation of a continuously improving organization. It is the application of quantitative methods and involvement of people to improve all the processes within an organization and to exceed customer needs.

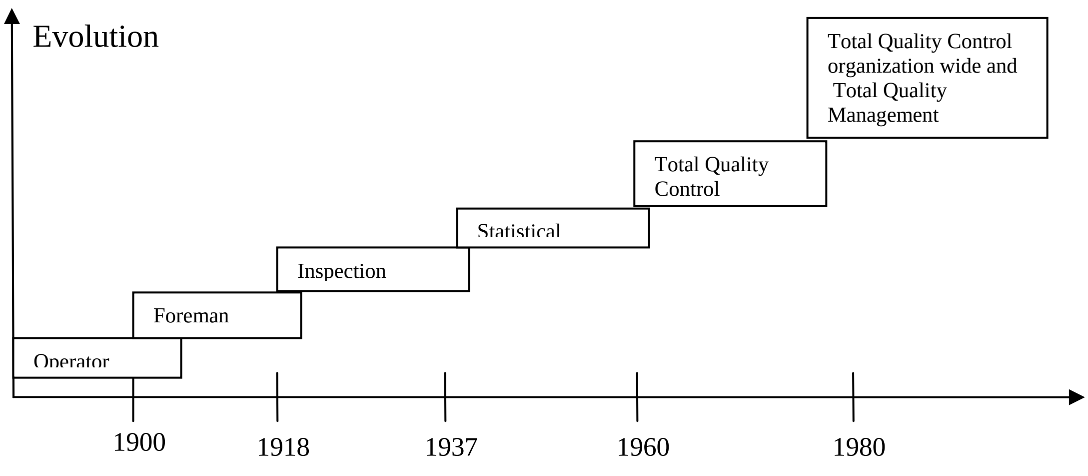

Figure 1: Historical evolution of quality methods (Feigenbaum, 1991)

Deming advocated that all managers need to have what he called a System of Profound Knowledge (SPK) (Deming, 1986). After being invited to Japan, Deming introduced SPK in the late 1940s and early 1950s where he also visited Toyota and taught his 14 key principles for management (Deming, 1986). It needs to be noted that the established problem solving process called PDCA cycle can also be traced back to Shewart and Deming.

Total Productive Maintenance

TPM began in the 1950s and focused primarily on the preventive maintenance (Wireman, 2004). The first company wide preventive maintenance initiative can be traced back to Nippondenso in Japan in 1960. As the automation level of Nippondenso increased, more maintenance personnel were consequently required. This led to the management decision that the routine maintenance of equipment would be carried out by the operators (autonomous maintenance) (Venkatesh, 2007). Those equipment management strategies were designed to support the Total Quality Management strategy (Wireman, 2004). In the 1970s, TPM evolved to a comprehensive system based on respect for individuals and total employee participation.

Comparing TQM with TPM the two methodologies coincide in most of their principles and strategies. According to Dale, TPM is complementary to TQM and can serve as an additional driver (Dale, 1993). The authors see a special focus of TPM on the elimination of downtime and loss (expressed in the emphasis on overall equipment effectiveness) (see (Jostes and Helms, 1994)) and on the involvement of shopfloor team members. Kedar et al. state that TPM is suited to companies which have a lower degree of improvement maturity, as TPM offers techniques like 5S, that can be seen as basic requirements for further techniques (Kedar et al., 2008).

Theory of Constraints

Theory of Constraints (TOC) was introduced by E. Goldratt in his business novel 'The Goal' in 1984. (Goldratt, 2004). The core of this theory resembles Liebig's law which states that growth is not controlled by the total of resources available, but by the scarcest resource (limiting factor). The roots in a manufacturing environment can be traced back to the development of a commercially successful shop floor scheduling software product known as optimized production technology (OPT) in the late 1970s (Jacobs, 1983). It needs to be noted that TOC does not have its origins in the automobile industry and found applicability in various industry fields. Based on this core principle Goldratt postulates that every organization has at least one constraint which limits the organization's overall performance according to its goals. To improve the overall performance of the system Goldratt developed five focusing steps. By improving and 'exploiting' the constraints the throughput of the whole system can be increased. Additionally TOC states that non-constraints need to be 'subordinated' to the constraints, as improvements in those areas will probably only lead to additional work in progress and inventory. The main technique for the coordination of constraints and non-constraints is drum-buffer-rope (DBR).

Toyota Production System and Lean Production

The term 'Lean Production' received public attention through the book *The machine that changed the world* of J.P. Womack and D.T. Jones (Womack et al., 1990). Womack et al. compared within a MIT study Toyota's manufacturing practices with its American and European rivals and summarized the findings under the term 'Lean Production'. Therefore the term 'Lean Production' needs to be understood as a Western reflection during the 1990s of Toyota's manufacturing methodologies. In the early phases Womack defined Lean as a systematic way of removing waste and Lean Production as a "superior way for humans to make things.…Equally important, it provides more challenging and fulfilling work for employees at every level, from the factory to headquarters" (Womack et al., 1990). In developing TPS, the objectives were to shorten production and set up time, integrate suppliers, eliminate waste, synergize the entire business process, and to gain support at all levels for this system (Spear and

Bowen, 1999). The Toyota Production System can mainly be described as an effort to make goods as much as possible in a continuous flow (Ohno, 1988).

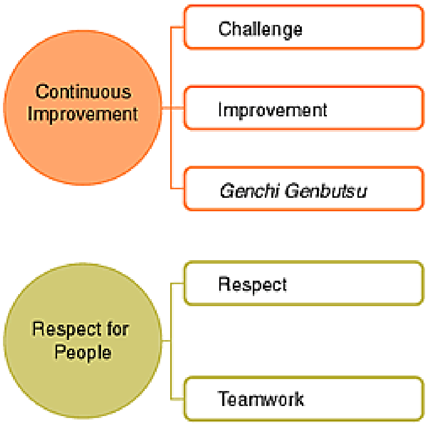

Figure 2: The Toyota Way main elements (Liker and Hoseus, 2008)

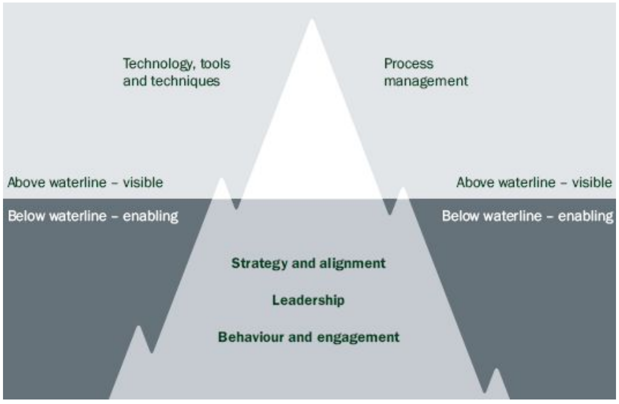

Figure 3: Hines' iceberg model of a sustainable Lean organization (Hines et al., 2008)

Ohno defines as the two main pillars of TPS: Just-in-Time and autonomation (Ohno, 1988). Just-in-Time refers to the ideal state of a flow system where the right parts reach the assembly line at the time they are needed and only in the amount needed. This will lead under ideal conditions to zero inventory. The second pillar, autonomation or also called Jidoka, represents the ability of machinery to stop immediately as soon as processes are out of the defined specifications.
In recent internal publications (The Toyota Way, referred to in (Liker and Hoseus, 2008)) Toyota emphasizes the importance of some elements of their corporate culture (see Figure 2, Genchi genbutsu means "Go and see for yourself") and placed lean tools like kanban and cells as a subset of the foundational element of continuous improvement (kaizen). If kaizen is broken down further in Toyota's model one gets the sub-elements of kaizen, mind and innovative thinking, building lean systems and structure, and promoting organizational learning. Recent literature ((Mann, 1995) (Liker and Hoseus, 2008) (Hines et al., 2008)) sees Toyota's success not only grounded in the manufacturing methodologies but even more in their management system and their corporate culture which is based on long-term thinking, respect for people and the responsibility of leaders to be teachers and trainers (see Figure 3).

Six Sigma

Six Sigma was started in Motorola by engineer Bill Smith in the late 1980s in order to address the company's chronic problems of meeting customer expectations in a cost-effective manner. Within improvement projects quality problems were systematically analysed at the front end of the process and continued throughout the manufacturing process using four phases (Measure, Analyse, Improve, Control). Jack Welch, the CEO of GE applied this program across all of GE integrating training of Six Sigma into the promotion structure. GE added an extra phase to define and manage improvement projects. Therefore the Six Sigma methodology offers an organisational structure where certified experts (Master black belts, black belts and green belts) lead the improvement projects. According to Kedar et al. Six Sigma gives clear change of structure and is much more orientated on fast and tangible results in comparison with TQM, TPM, and

Lean (Kedar et al., 2008). Hereby the main focus lies in the elimination of variation in processes in order to achieve immediate cost savings.
Näslund concludes that Six Sigma is a further development of TQM. He found similarities in the problem solving process (Deming wheel and DMAIC cycle), the importance of top management commitment, the necessary employee involvement, and in statistical methods (Näslund, 2008).

Lean Six Sigma
Lean Six Sigma adds, according to Hambleton, the concepts of velocity, value-add and flow to the DMAIC concepts and is therefore to be seen as a consequent combination of Lean Production and Six Sigma (Hambleton, 2008). Hambleton mentions that DMAIC provides the big picture view, process stabilization and capability – while Lean introduces speed, the elimination of waste between processes and flow concepts at a more detailed level. Lean concentrates on process timing – overall cycle time, including the timing between process steps by removing non-value-added activities. In summary Hambleton sees Lean as an important part of the Six Sigma ‘arsenal’ and considers it as an important cornerstone of the Six Sigma approach. Muir argues that Six Sigma techniques focus on fixing processes whereas Lean methodologies concentrate on the interconnections between processes (Muir, 2006).

Lean, Six Sigma and TOC
Dahlgaard (Dahlgaard and Dahlgaard-Park, 2006) concludes in his comparison of Lean Production, Six Sigma and TQM that both Lean Production and Six Sigma comprise management and manufacturing philosophies and concepts, which have the same origin as the methodology TQM. Additionally he concludes that the principles, concepts and tools of Lean Production and Six Sigma should not be seen as alternatives to TQM but rather as a collection of concepts and tools, which support the overall principles and aims of TQM.
Nave compares Six Sigma, Lean Thinking and Theory of Constraints (TOC) based on which theory, focus and underlying assumptions are inherent (Nave, 2002). The theory, its focus and the underlying assumptions will lead to primary and secondary effects which are quite similar (e.g. secondary effects for all three programs are improved quality and less inventory). While describing them all as “improvement programs” Nave identifies as the primary theory of Six Sigma the reduction of variation, the reduction of waste as the one of Lean Thinking and the reduction of constraints as the theory of TOC. Six Sigma focuses on existing problems, Lean Thinking puts its emphasis on flow, whereas TOC has its focus on the constraints of the system. In the opinion of the authors flow and the exploitation of constraints are causally interdependent. Identifying the overall constraints of a system, exploiting those and subordinating all non-constraints, are necessities to achieve an improved flow through the system.
Dettmer argues that since TPS was not formally known by that name in America until Ohno’s book “Toyota Production System”, other terms such as statistical process control, concurrent engineering, cause-effect analysis, five why’s, team work, supplier/supply chain management, horizontal integration, and just-in-time gained wider recognition instead. And the collection of these (and other) tools came to be generally known as “total quality management” or “continuous process improvement.” (Dettmer, 2001)
There is a growing body of literature (see Figure 4) (e.g. (Dettmer, 2001), (Srinivasan et al., 2004), (Spector, 2006), (Gupta and Snyder, 2008), (Youngman, 2009)) that analyses or compares the methodology of TOC with Lean Production or other methodologies. Some authors conclude that TOC serve as a focusing mechanism where to apply Lean

techniques and Six Sigma techniques to achieve best results for the overall system. Figure 4 shows the steadily growing number of publications with the keyword "Theory of Constraints".

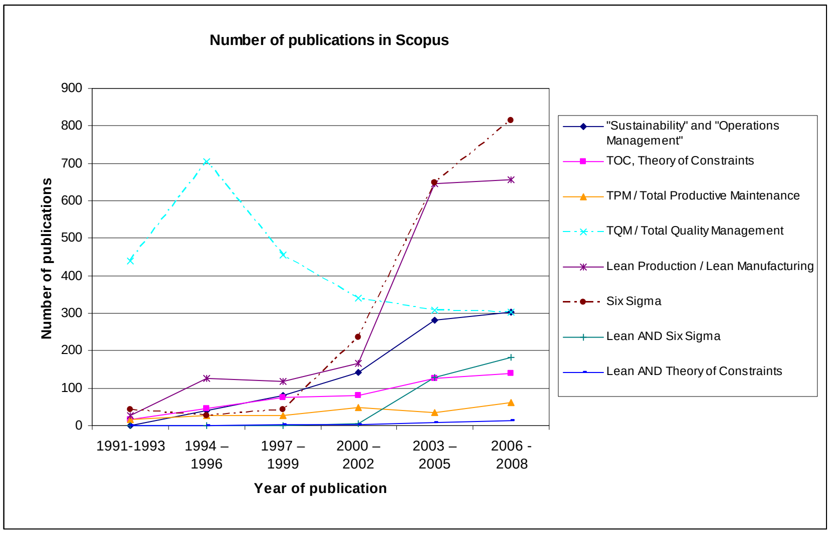

Figure 4: Number of publications with keywords in title or abstract in database Scopus

Overview of methodologies

Table 1 gives an overview of the origins, the focus and the aspects that are in the opinion of the authors distinctive, based on the analyzed body of literature and own experience.

Table 1: Overview of methodologies

	TQC / TQM	TPM	Theory of constraints	Lean (JIT, TPS)	Six Sigma
First mentioned	1960s / 1980s	1970s	1984	1988 (Krafcik)	Late 1980s
Origin	'Gurus' like Shewart, Juran, Deming, and Crosby	Nippondenso	Goldratt	Toyota (Toyoda, Ohno and Shingo) and NUMMI (Womack and Jones)	Smith of Motorola and General Electrics
Focus	Reduction of variation, quality of processes and product	Waste, loss, reduction of downtime	Exploitation of constraints and subordination of non-constraints to the constraint in order to increase throughput	Value creation – material and information flow/pull - perfection	Reduction of variation
Distinguishing and value adding contribution	Statistical Quality Control, involvement of other departments, process orientation, the reduction of variation increases quality	Team involvement on the shop floor, preventive maintenance leads to reduction of downtime, a higher process capability; zero defects.	Focus mechanism on constraints	Pull, takt time, heijunka, one-piece-flow, value stream mapping, respect for people	organisational structure with improvement experts (black belts and green belts), project oriented, quantification of cost savings

From Taylorism and Fordism to Toyotism

Figure 5 chronologically summarizes the evolution of manufacturing methodologies based on the dates of the earliest publications known to the authors. Further the main needs and main drivers are presented and explained below.

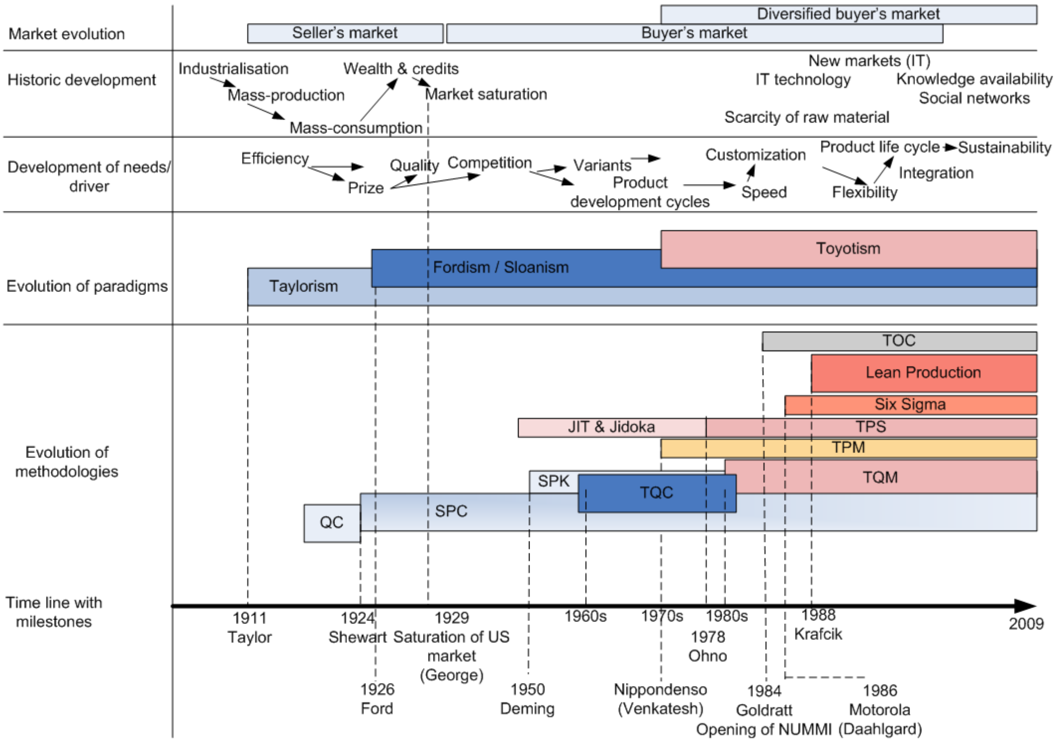

Figure 5: Historical development of manufacturing methodologies and its drivers and needs

In the early 20th century the automobile market was clearly dominated by the manufacturer as seller. The Taylorist reorganization of production increased the productivity of labour (referred by (Souza, year unknown)). The main underlying principles are the division of labour dividing tasks into simple repetitive movements which is based on the interchangeability of parts. This division of labour led to a clear differentiation between the activities of planning and execution and consequently to a separation of mental and physical work. Souza mentions the so-called classical management model which mainly emerged out of the contributions of F. W. Taylor and H. Ford. The expression of Fordism was coined by Gramsci (1972) and reflected the automobile assembly line dominated thinking. In Fordism, teams were not that necessary, as individuals were responsible for discharging job tasks defined by engineers (Kenney, year unknown). Ford's production system fulfilled the need of a growing economy and its characteristic as a seller's market and built the basis for mass-production. According to Souza the classical management conception was successful until the 1970's when economic, social and political contexts changed the world markets and caused economic recession. The ability of mass-production sparked an era of mass-consumption which led to a reinforcing loop. The more efficient and sophisticated the means of mass-production became, the faster and cheaper the still growing market could be satisfied. The state of a seller's market and the reinforcing loop of the ability of mass-production and mass-consumption found its limitations in industrial countries because of the saturation of consumer-goods. The American automobile market showed first signs of saturation in the late 1920s (Flink, 1990). In 1927 the share of new cars sold on time dropped from 73 % (1922) to 58% which was accompanied by an estimated decline of $643 million in the volume of instalment sales of both new and used cars (Flink, 1990). According to George, competition for market shares rather than the continued growth became a major concern (George, 1982).
When after WW II the automotive industry in Japan started again, Toyota did not have the financial strength to invest in specialised expensive mass-production manufacturing

technologies. Additionally they faced the problem that the smaller Japanese market compared with the American asked for an increased product variety with smaller lot sizes (Liker, 2003). After the owner of the company, Eiji Toyoda, visited Ford in 1950 in the USA together with his leading production engineer Taiichi Ohno, they realised that the inflexible and capital-intensive mass-production does not fulfil the requirements of the Japanese market and surrounding conditions and designed their production system to face their specific constraints (Fujimoto, 1999). Vogel refers to the limited resources of Japan and the herewith evolving "specific organizational structures, policy programs, and conscious planning" (Vogel, 1979) as the main sources of their success. The main manufacturing methodologies of the Toyota Production System, Just-in-Time and autonomation, have been started in Toyota around 1945. Though those methodologies hadn't come to more public attention in Western industries and Western academia until the 1980s ((Schonberger, 1982), (Ohno, 1988), (Shingo, 1989), (Womack et al., 1990), (Monden, 1993)). As the Japanese market saturated in the 1970s, Japan started to target export markets. This led to an intensified competition in the American and European automobile market.

Kenney elaborates that in a competitive world with ever-shortening product life-cycles, the ability to motivate workers and the power to increase the intellectual part of products and consequently the creation of new knowledge are central to corporate viability. In a consequence the usage of humans for physical activity is of less significance as a source of value. The need of not only producing but continually improving production led to close connection of research and engineering to production and the awareness that learning-by-doing and training are not goals by themselves but they are necessary to create means by which to improve production (Kenney, year unknown). The effects of saturation on the concept of a mass-production system have been amplified by the growing awareness of the scarcity of raw materials and by the trend of diversity caused by the increase in income and wealth (Piore and Sabel, 1984). It is obvious that the scarcity of raw materials (e.g. USA reached its maximum oil production in 1972 (Energy Information Administration, 2008)) and the capacity of the planet to cater for increased production and effects on the environment (Victor, 2008) will have a significant influence on our current understanding and meaning of manufacturing methodologies. In this context, elimination of waste und the need of sustainability will keep its validity and will further gain importance. This can be confirmed by a growing number of publications on sustainability with regards to the areas of operations management (see Figure 4). Current manufacturing methodologies base on the policy of increasing operational efficiency by reducing costs or increasing throughput. The hidden assumption of continuous growth of markets and demand is existential to the efficacy of the current manufacturing methodologies. As the scarcity of raw materials and energy resources will increase in the next decade(s) the concept of ever growing markets and economies becomes questionable. It is indisputable that the elimination of waste and continuous improvement regarding quality and timeliness are fundamental necessities in order to stay competitive. But in the opinion of the authors the need of long-term sustainability requires a supply chain integrating systemic approach which takes the whole life cycles of resources (raw material, energy, secondary use) and of products into account. Therefore, changes in operations management from a focus on local optimizations (Youngman, 2009) (e.g. linear programming, MRP scheduling) and a "mechanistic" linear cause-effect perspective (Johnson, 2007) to more systemic optimization efforts taking into account nonlinear complex cause-effect connections (living systems) will become necessary.

Conclusions

The paper explored the historical evolution of manufacturing methodologies and discussed their distinctive characteristics and their similarities. The analysis of content and origins shows a clear evolutionary common thread from Taylor to Ford, and from Deming to Toyota's interpretation. Toyota has clearly designed a manufacturing system that integrates contents of all mentioned methodologies in order to address the drivers and needs that resulted out of the market saturation. Therefore Toyota operated in a more superior manufacturing paradigm based on the pull rather than push philosophy. But the authors believe that Toyota did not invent a new management paradigm as their business assumptions are obviously derived from Deming's and Ford's managerial philosophies and have been available to the competitors as well. Additionally Toyota's superiority which has been reconfirmed by recent developments lies in the more consistent interpretation of Deming's and Ford's managerial philosophies, e.g. on systemic long-term commitment to the responsibility for staff and society (compare with (Liker, 2003), (Liker and Hoseus, 2008)) .

TOC seems to be the only methodology having an independent origin which could be a sign of an evolving new manufacturing paradigm. Recently published literature comparing TOC or discussing its combination with other methodologies indicate its superiority ((Nave, 2002), (Srinivasan et al., 2004), (Spector, 2006), (Gupta and Snyder, 2008)). Therefore the authors believe that Operations Research may have a future emphasis on extending the body of knowledge about TOC. Having the slowed down growth of global markets and economies and the current financial crisis in mind the constraining factors are more drastic. Operating and managing within given constraints (resources, policies…) has become more obvious. Also Johnson remarks that one of the main challenges of 'Lean management' in the sense of running companies according to living system principles will be to conduct our "economic activities within the limits of Earth's regenerative processes." (Johnson, 2007)

Additionally the driver of an increasing scarcity of resources will amplify the needs for more sustainable solutions in the long term. More holistic and systemic approaches aiming to solve global optimization problems in a non-linear complex environment will be necessary.

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