STEP-BY-STEP APPROACH TO OPTIMIZE COMPLEX PRODUCTION PROCESSES

Evolution, not Revolution

Swen Günther, Rothenkirchen, May 2015

Abstract

The improvement of production processes in companies often bears the character of an "Evolution" instead of "Revolution". Depending on the reference period chosen, the processes are changed step-by-step in order to make them more "robust" against external influences. This incremental approach makes fully sense from evolution-theoretical point of view.

At Procter & Gamble (P&G) site Rothenkirchen, the Reliability of complex packaging lines has been increased significantly in past few years. Retrospective, this can be explained by the (implicit) application of an evolutionary process model IESRM in contradiction with many conventional management practices, i.e. PDCA. The article outlines how IESRM model can be easily adopted into daily business via a Daily Direction Setting (DDS) approach.

Challenge: High complexity Manufacturing

Manufacturing sites with complex, highly automated production lines are constantly challenged to maximize the reliability of each individual process in order to minimize the probability of failure of the entire line. This situation can be well observed on production lines where individual units are connected "in series". For example, at P&G Rothenkirchen hair coloring products for Retail market are filled and packed on production lines with up to 15 – more or less complex – individual aggregates.

A common choice in companies is to use the 5M influences (machine, method, material, ...) but this can lead to unplanned line stops and thus downtime. In addition to low productivity, there is also an increased quality risk, because each stop can lead to product failure, increased rejections and / or declaration errors. In addition, each stop carries the risk of generating a next stop during the restart of the machine: "Stops breed stops!"

Therefore, a strict "zero-stop" strategy has been followed for years in more than 130 of P&G´s manufacturing sites around the world. As it is easy to understand, this can generate an enormous economical success. In order to increase the reliability of a production line, there are – by definition – two approaches from management perspective:

- Synoptic - Large steps, i.e. improvement projects related to known problem areas are initiated and carried out over a longer period of time.
- Incremental - Small steps, i.e. specific actions are carried out on a daily basis to locate and preferably, eliminate causes for line stops.

In both cases, however, a practical barrier is given since the problem solution itself cannot be scheduled because the root cause of the problem is – by definition – unknown. Regular workshops can be scheduled in order to figure out the root cause for a given problem, and/ or to execute actions for well known problems to remove the stop reason(s). Under these conditions, the "State of the Art"-Management philosophy of PDCA cycle (Plan, Do, Check, Act) is not sufficient neither to provide an efficient, nor effective problem solving cycle.

Based on relevant experience and selected case studies, the following can be shown for the optimization of complex human-machine systems: An evolutionary approach based on the natural biological process is more appropriate to solve complex (real) problems than a rigid, mechanistic approach which is based on analytical cause-and-effect chains. These are generally more difficult to detect in an environment of stochastic processes with a large number of parameters than in an environment of deterministic processes (for specification of IESRM cycle see box). Therefore, an "improvement in small steps" is more promising than the launch of major improvement projects.

Table 1 lists the most important terms that are relevant in the context of natural evolution, listed and assigned to the subject area "Enterprise".

Goal: Less unplanned Downtime

At P&G Rothenkirchen, the reliability of packaging lines has increased dramatically in recent years. The key performance indicator Mean Time Between Failure (MTBF) as mean time between two unplanned line stops has increased up to five times within three years, from 20 to more than 100 minutes. The increase is not explained by the daily application of the PDCA cycle, but by the application of an evolutionary process model based on five phases: Initialization, Evaluation, Selection, Recombination and Mutation (IESRM cycle, Figure 1 and 2).

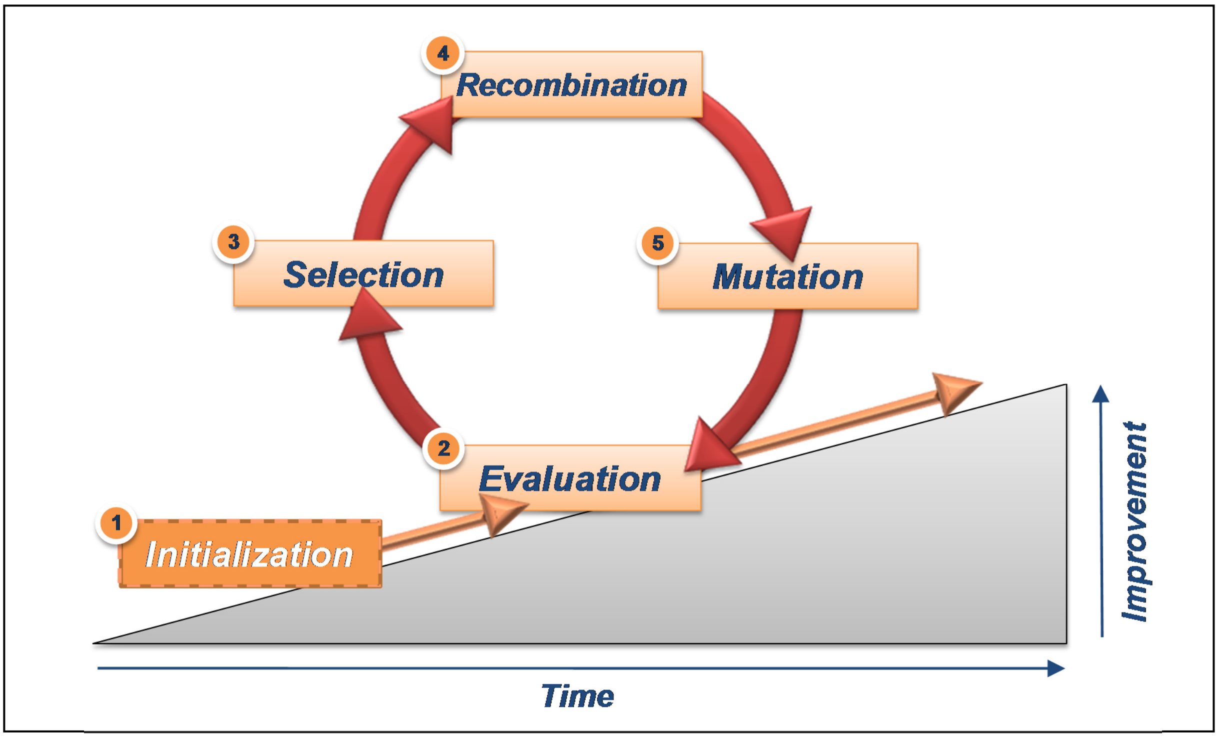

Figure 1: IESRM – Evolutionary Improvement Cycle with Five Steps

Initialization

P&G Rothenkirchen is staffed for a 3-shift-operation with fixed teams, and a partly varying aggregate/ system accountability. Technical support (mechanics, electricians) for problem solving are available offline, i.e. during day shift. The Quality and Logistics departments are planned and managed independently from Operations. The lines run at a speed of more than 100 pieces / min and achieve a throughput of two orders of 4,000 pieces per hour. Line layouts and machinery are mostly standardized and set in U-shapes. After palletizing, the finished product is shipped directly. The complexity of production is mainly driven by a high number of finished products (~ 5,000 finished product codes).

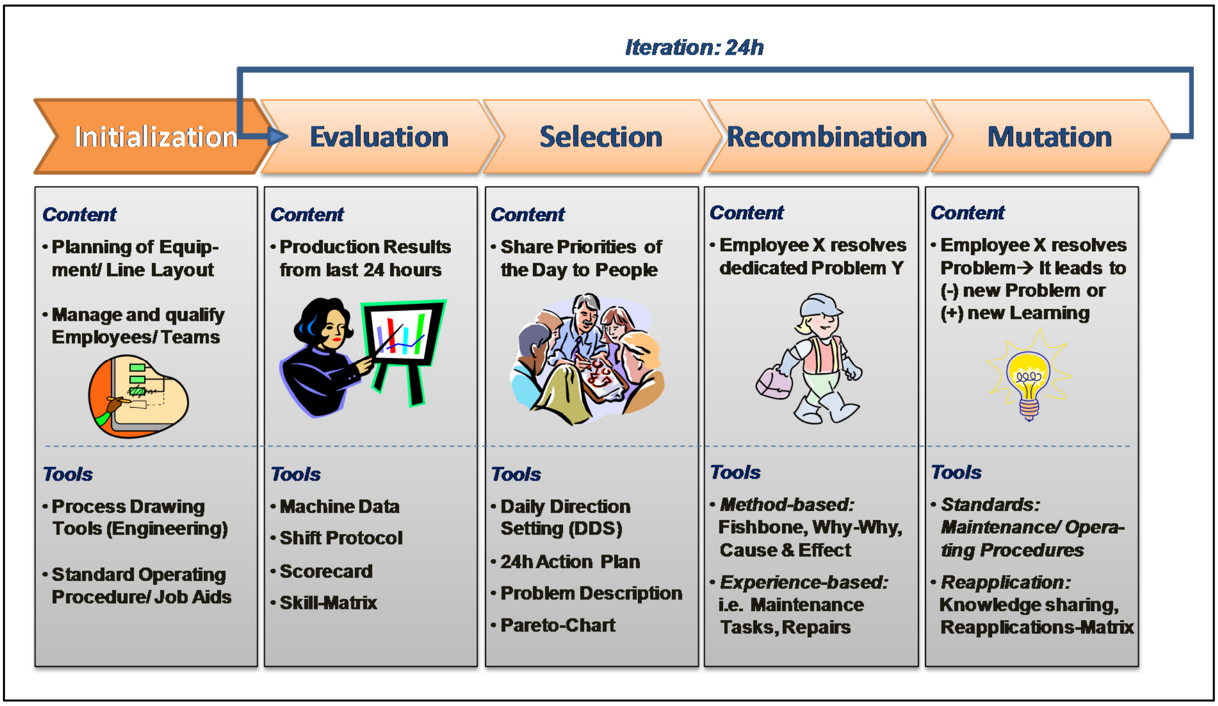

Figure 2: 24 Hours Cycle – Overview of Phases, Contents and Tools

Evaluation

Starting point for any improvement is the evaluation of the current situation. Therefore, according to the evolutionary approach, the fitness of a population of individuals has to be determined. For enterprises, in analogy, it can be described as the determination of the performance of production lines. Simply spoken, production lines are a collection (population) of humans and machines whose "interactions" have to be improved over time. At P&G, MTBF measures line performance and indicates, overall, the Fitness of designated production system. Based on real-time data acquisition system (Proficy), MTBF results are tracked for each production line worldwide. P&G is able to benchmark the process reliability of production lines with the same or similar machinery.

The MTBF results are shared every morning from past 24 hour production in the so called Daily Direction Setting (DDS) meeting with the participation of line staff, shift and line leaders as well as technical support personnel, i.e. maintenance, electrics. Among others, the actions of the previous day are reviewed in order to ascertain if they were properly processed and, hence, have contributed to an MTBF increase. Indirectly, this helps to evaluate the capability (fitness) of the employees to solve problems on the line independently. If there are skill gaps evident, then an update of the so-called skill matrix of the employee is immediately carried out. This is alongside with the continuous development program of the technical capabilities of line operators; an important learning in Rothenkirchen.

Selection

The unplanned line stops, from the last 24 hours, are aggregate-based and shown in a histogram, visualized on the team board. Ideally, the three most frequent stops (Top 3) of the previous day are selected for processing on the current day. The responsible shift leader assigns tasks and actions to persons involved, such as engineers, electricians, operators or employees of other departments, i.e. Logistics. An important tool to figure out the (root) cause of a designated line stop is PUA (Problem, Cause, Action). The issue, including a sketch, as well as preliminary findings and counter measures are handwritten documentation based on a template. Latter acts as a "ticket", which is closed only when all actions have been processed and the observed line stop no longer occurs.

Recombination

In nature, "recombination" is described as intersection or exchange of genetic codes of two individuals (parents) with the aim to improve the fitness of the emerging individuals (children). This mechanism is also found in organizations, but in a different form: instead of "recombination" we should rather speak of "regeneration". Transformations in machines, on the one hand, and employees on lines, on the other hand, act as "parents". Line stops are caused by faulty process steps and/ or transformations that have to be repaired (regenerated) at regular intervals, i.e. maintenance workshops. In a simplified conceptual model, we are able to understand the sequence of n transformations as binary-chain (1 1 1 1 0 1 1 1 ...) whereas "1" stands for transformation = ok and "0" for Transformation = not ok.

As a counterpart (and second parent) to the machine transformations, there are the employees, equipped with their specific knowledge and problem solving skills. These skills, greatly simplified, can be represented in the form of binary codes, too, whereas, "1" stands for existing knowledge to solve the technical problem and "0" for non existing knowledge. Hence, humans and machines are problem and solution candidates at the same time: their genetic (binary) codes are recombined in such a way that the employee knows the solution to a specific issue, e.g. provided in the DDS morning meeting. He/ she would then be able to regenerate the transformation in question during the day. If the fix is successful and the transformation works perfectly, the genetic code of the machine switches back from "0" to "1".

Mutation

Mutations are random changes in the genetic code, which usually affect adversely the fitness of the individual. Accordingly, in the binary representation of machine setup, mutations enforce the switch from "1" to "0". In the business environment, the random changes of transformations can be caused by the following factors:

- stochastic influences over time, such wear of components, and
- ineffective troubleshooting, i.e. due to skill/ knowledge gaps.

In order to minimize the occurrence of mutations, operational procedures have to be standardized. Therefore, P&G has introduced a variety of standards to ensure that repetitive tasks and processes are performed with consistently high quality. Standard Operating Procedures (SOP), i.e. start-up procedure for production lines and work instructions for cleaning/ maintenance of machines, are the “bottleneck” of complex production processes. They are trained and checked at regular intervals to all employees. Leadership ensures observance of these SOPs.

Only very rarely, mutations are beneficial and result in “innovation”. This can happen, when employees gain new insights during maintenance and/ or troubleshooting, leading to an improved solution that advances the performance (fitness) in general, i.e. an additional sensor is installed to detect material defects. Due to this new transformation, the genetic code of the machine is extending. To standardize innovations, P&G has established a change management system where all technical changes are controlled for reapplication to other lines.

By reprocessing the phases of Evaluation, Selection, Recombination and Mutation every day, the average fitness (performance) rises in the form of an S-curve over time (Figure 3). The course is not continuous, but varies depending on the day. As mentioned above, this variation is caused by a large number of (random) influences that need to be mastered in the long-run, i.e. materials from different suppliers. As a result of technical or organizational changes major setbacks may occur in the MTBF development, i.e. installation of new equipment or introduction of new teams. In these cases, there will be a re-initialization of the evolutionary process, which again leads to an increase of fitness over time. Typically, after each re-initialization, the average fitness develops as an S-curve again.

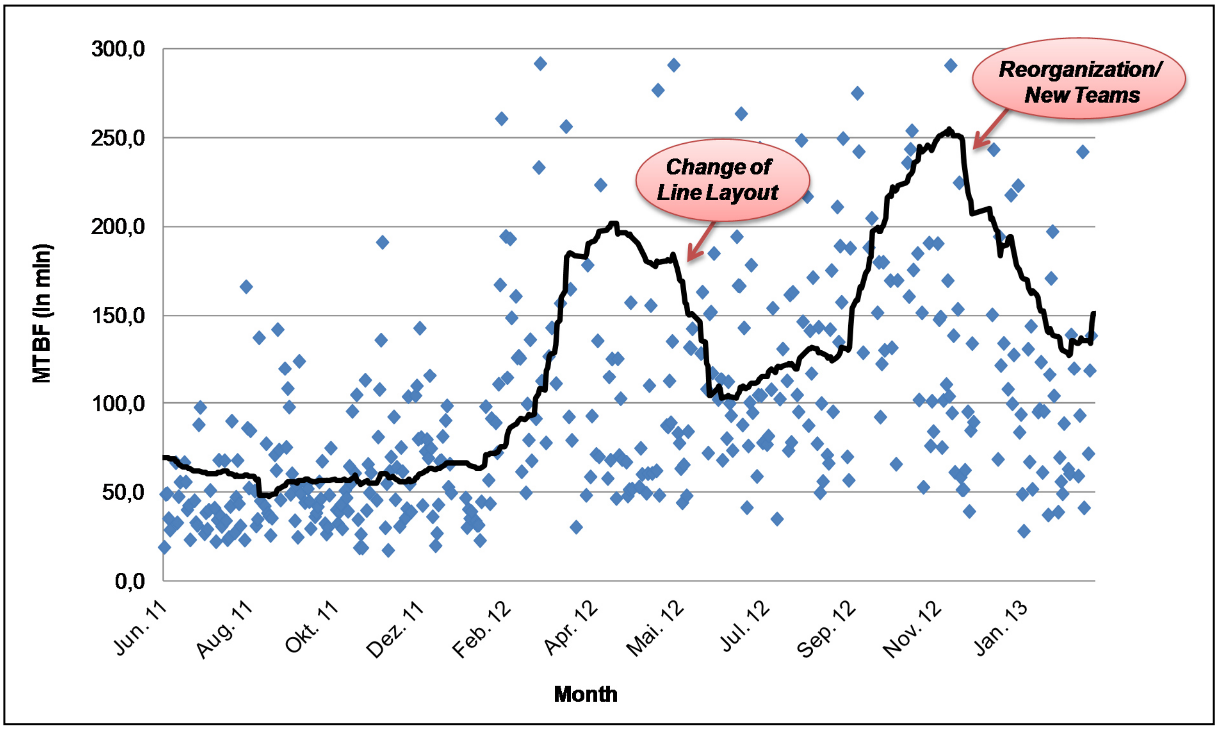

Figure 3: S-Curve – Development of Production Line Performance (MTBF, Example)

Result: Daily Small Improvements

The example P&G Rothenkirchen shows that it is possible to increase the reliability of complex production lines by using simple, wide-ranging tools on a daily basis. The development of target figure (fitness) follows an evolutionary pattern, rather than a revolutionary. The IESRM cycle allows a conscious management/ control of this evolution. Companies are not a "pinball" of evolution anymore, but they can be an active partner. Advantages and disadvantages of this new approach are summarized in Table 2. The points mentioned so far are based on qualitative and anecdotal evidences and so must first prove themselves in the course of further practical applications. During the project, several other *general Leanings* were made and can be shared here:

Diversity is King! For the continuous improvement of reliability of complex production lines a pool of people shall be (daily) available that recurs as wide a range of skills, experiences, ages and genders, i.e. operators, engineers, planners, maintenance staff, process engineer, shift leader. This ensures a quick and broad-based approach to problem definition and solution search.

Good Data Needed! The assessment of the line results, as well as decisions made during DDS process, should be based solely on data and facts. Therefore, a production data acquisition system is necessary, which can be edited by the operators but is secure from manipulation. In addition, information on issues, faults, stops have to be gathered via standardized (shift handover) protocols, where problem sketches are included.

Capability Check, Daily! Beside line stops (MTBF) that are tracked on a daily basis, the skills of the employees who were involved in problem on day before have to be evaluated in a timely manner. A (semi-) annual update of the skill matrix of employees is usually not sufficient in today´s highly volatile environment with fast changing requirements.

Workshops Can Help! Some "chronic problems" that are rare, but occur at regular intervals, can not always be eliminated by using a 24-hour problem solving cycle. Greater efforts are needed to solve the issue. Therefore, focused improvement workshops have to be launched from time to time. At P&G Rothenkirchen, we established teams of 4-5 employees who worked (fulltime) on a specific problem for 2-3 days. A step-by-step methodology ensured sustainable solutions.

Changes, step-by-step! From nature, we know that great changes (of genetic code) reduce the fitness of organisms rather than increase it. This law also applies to organizations when we consider them as living organisms. Hence, planned technical and/ or organizational changes, i.e. a planned new line layout, should be executed sequentially rather than in parallel, even if the last one is often preferred for cost reasons. Evolution wants to preserve appropriate set-ups/ characteristics.

Discipline, Discipline! This relates directly to the implementation and execution of the Daily Direction Setting (DDS) meeting: every day, with a fixed time zone, fixed group of people and standardized agenda. Only in this way a continuous improvement process is set in motion. Because the DDS ensures that even on days when the line results are "good", they are an environment to eliminate chronic problems. At the same time, it is avoided that people overreact on "bad days".

Servant Leadership! At the end, "It all starts with leadership!" is the basic rule for every successfully implemented management concept. At P&G Manufacturing, all managers, from the line to the plant manager, are requested to be on the floor every day in order support operational staff in the problem definition and resolution. In addition, they act as a coach and act as a role model in terms of compliance with standards, the implementation of actions and the removal of barriers.

Natural Evolution	Corporate Context
Individual Organism	Human-Machine-System
Fitness as overall Target	Performance, i.e. Reliability of production line
Pheno- vs. Genotype Level	Real, observable production process vs. Abstract representation of machine data
Genetic Variation	Diversity of employee skills and technical components
Genetic Code (DNA)	Transformation as lowest common process step of an equipment
Recombination as cross-over of genetic codes	Binary code representation of Transformations, incl. recombination at cognitive level
Mutation as random change of DNA	Natural wear, Machine breakdown, Operating Error etc. that causes Binary-code changes
Generation (Parents, Children)	Iteration of evolutionary phases, e.g. on a 24-hours basis

Table 1: Definitions of Natural Evolution in the Corporate Context

Advantages	Disadvantages
Evolution of (complex) Human-Machine-Systems of Manufacturing sites is *consciously* controllable	Limited view, if enterprises are – in general – regarded as „living organisms“
IESRM-Zyklus can be *easily* integrated into daily business via Daily Direction Setting (DDS)	IESRM cycle in daily business requires high grade of *discipline* of all participants
Low qualification effort needed since dedicated tools are widely used in corporate practice	Great simplification of genetic algorithms: Codes are recombined *intellectually*, not in reality
No (pre-)knowledge / Skills needed regarding potential Cause-and-Effect-Relations	Result/ Outcome is noticable after long period of time or many iterations of ESRM cycle
Under given conditions: Theses and concepts derived from evolutionary theory, i.e. S-Curve, can be transferred to enterprises	Difficult to apply in small enterprises with few employees (small population) and few process parameters (low complexity)

Table 2: Advantages and Disadvantages of evolutionary improvement cycle IESRM

Continuous Improvement via Evolutionary Algorithm

The *IESRM cycle* – similar to DMAIC and DMADV – consists of five phases: Initialization (I), Evaluation (E), Selection (S), Recombination (R) and Mutation (M). The last four phases are combined, forming an iteration loop, which lasts until an optimal solution from a customer perspective has been found. Analogous to the programming of EA and/ or GA, the solution principle is based on the simultaneous optimization of *n* solution candidates. The *population* is summarized at the beginning of the cycle, in the Initialization phase.

Following the natural evolution, the goal is to increase gradually the fitness of the whole population, and not only the fitness of a single individual! Thus, solutions (individuals) with outstanding characteristics can be "breed". On an overall perspective, the design and content of the single phases of IESRM-cycle are defined through the *five questions*:

- *Initialization:* What is the problem?/ Which product solutions already exist?
- *Evaluation:* How well do the solutions meet the customer requirements?
- *Selection:* Which solutions/ designs will be held?/ Which are sorted out?
- *Recombination:* How can we generate (still) better solutions from existing ones?
- *Mutation:* Which features of random changes result in improvements/ innovations?

The methods and/ or tools used in the various phases of the IESRM-cycle come mainly from the Quality Management and Innovation Management systems, e.g. Fishbone Diagram or Morphological Box. Similar to the Six Sigma improvement cycles, DMAIC and DMADV, they are interlinked so that a systematic problem solving approach is ensured: In the *Initialization phase*, the customer's problem and the project focus (in/ out) are specified in detail using a Team Charter. Next, in the *Evaluation phase*, the benefit (fitness) of each single solution (individual) located within the starting population is evaluated.

In the *Recombination and Mutation phases*, methods/ tools mainly based on the programming of GA, such as Rank-based Selection and Flip Mutation, are used. These phases ensure that, on the one side, the "genetic diversity" of the population is retained as long as possible and in the long run only the individuals with the highest fitness will succeed. On the other side, they promote random changes in the characteristic of the single individuals. By changing the Bit-String or "genetic code" randomly, innovations in the next iteration of ESRM-cycle may arise. In addition, Recombination and Mutation phases increase the likelihood of detecting specific customer requirements and thus potential market niches.

References

Günther, S. (2014): Evolution statt Revolution, in: QZ, 59. Jg., H. 9, S. 10-15.

Günther, S. (2010): Design for Six Sigma – Konzeption und Operationalisierung von alternativen Problemlösungszyklen auf Basis evolutionärer Algorithmen, Diss., Wiesbaden 2010.

Günther, S./ Töpfer, A. (2010): Mutation und Selektion, in: QZ, 55. Jg., H. 12, S. 52-53.

Author

Dr. Swen Günther, born 1977, is QA Systems Leader at P&G Rothenkirchen (ex Wella site). Beforehand, he was an Area Leader of Professional Hair Color Products and responsible for Focused Improvement (FI) Pillar at Rothenkirchen plant. He joined the company in 2008 after he had accomplished his PhD at the Chair of Corporate Management and Marketing at TU Dresden under the supervision of Prof. Dr. Armin Töpfer.

Tel.: 037462-62649; E-mail: guenther.s.4@pg.com