Using Evolutionary Algorithms in the context of Design for Six Sigma

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Abstract

The importance of *Design for Six Sigma (DFSS)* as adaptation of the Six Sigma concept for Research & Development (R&D) continues to increase. However until now, the results achieved by the application of the concept are, in overall, not satisfactory. The main improvement area is the effectiveness of the problem solving cycles. They are relatively complex in their application and do not always lead to the desired results.

In this paper the development and application of an alternative problem solving cycle, based on the application of *Evolutionary Algorithms (EA)*, is described. The effectiveness and efficiency of this new approach is verified experimentally, as well as using empirical data, e.g. creation of new innovative products with high quality.

From technologically-based to biologically-based problem solving

DFSS stands for "practised Zero-Defect-Quality" within Product Development Process (PEP). The goal is to launch new products and/ or processes with 6σ quality, i.e. 99.99966% accuracy. In the past a number of phase-oriented cycles have been developed, i.e. DMADV, DMEDI and DCCDI. These cycles were based on the DMAIC cycle for improvement of existing products/ processes. In order to adapt to the different R&D strategies, and the credo of corresponding companies "From the Practice for the Practice", they were modified gradually over time. In the end, the five phase *DMADV cycle*, Define (D), Measure (M), Analysis (A), Design (V) and Verify (V), was left as the most spread in Six Sigma community.

According to several Six Sigma experts, the main reason for DFSS projects failure is linked to the existing *Trade-off* between the high quality of products on the one side and the high degree of innovation on the other side. Due to their Six Sigma heritage DMADV *et al.* cycles have a strong focus on the optimization of the "quality" dimension. In order to develop new products/ processes with zero-defect-quality, a systematic and analytical approach is used. Intuitive and creative processes, required for the generation of innovations, remain in the background. As a result, DFSS leads to robust, but little innovative products/ processes.

In order to resolve this problem, a scientific approach using abstraction and comparison based on algorithms used for solving problems in mathematical optimization, was developed. With the help of these algorithms, it is relatively easy to detect the methodological weaknesses of the DMADV *et al.* cycles. Additionally, alternatives on how to deal with (highly) complex and/ or unsafe situations become apparent. The mathematical optimization relies on the use of *Genetic Algorithms (GA)* which are configured on the pattern of natural evolution. To make the findings available to the industrial environment an appropriate (evolutionary) problem-solving cycle has been designed and implemented.

Evolutionary Algorithms increase the fitness of population

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 (see Figure 1). 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?

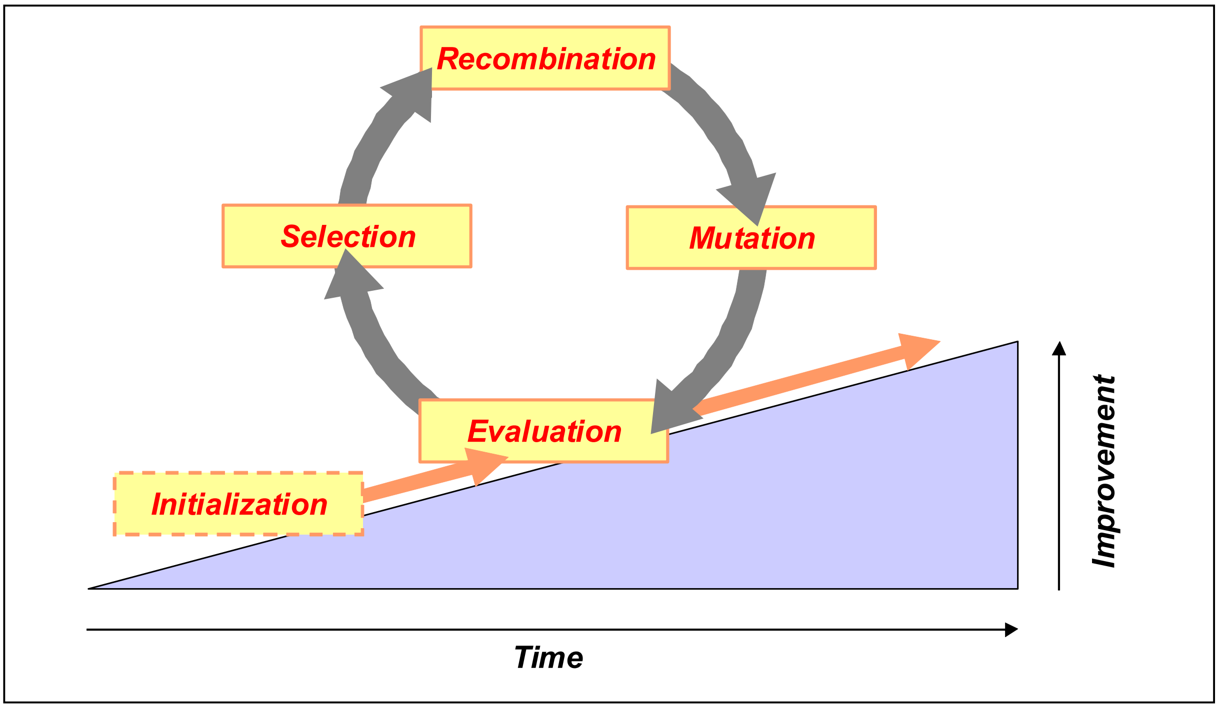

Figure 1: The five phases of IESRM-cycle

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.

Efficiency and effectiveness of the IESRM-cycle empirically proven

The strengths and weaknesses of the theory-based IESRM-cycle were investigated as part of a *Business Case Study*. For the first run a relatively simple product, namely a brush for street cleaning, was selected. In cooperation with the Michael Jäckel Erzgebirgische Bürstenfabrik (EBF), a mid-size company with a large portfolio of brushes, a new standard broom with optimal brush characteristic was developed.

Although being a *Critical-to-Quality requirement (CTQ)*, cleaning characteristics have not been a subject of systematic analysis and/ or optimization so far. Traditionally, all R&D efforts were focused on the adjustment of brush designs to different application areas, e.g. cleaning of coarse and fine dirt, sweeping on wet and dry surface. The new brush for street cleaning, developed using the IESRM-cycle, combines the strengths of several product variants. Most of these variants were already included in the current EBF product portfolio.

In order to create an optimal design, a (new) standardized measurement method for evaluating the degree of brush effectiveness was developed. A log-function measure was the basis for the determination of *Fitness values*. In accordance with the natural evolution, designs with the highest fitness were selected after each run of the IESRM-cycle. The best solutions came into a "mating pool" in order to crossover their genetic codes. In this way, the average fitness of the population was increased by more than 100%: After five iterations, only brushes with excellent cleaning characteristics were left.

In addition to the business case study, the efficiency and effectiveness of IESRM-cycle were proved experimentally at the *University of Dresden*. According to empirical data, the results achieved with the use of IESRM-cycle have *outperformed* these of DMADV-cycle. From a customer perspective, the IESRM-cycle is characterized by high accuracy in finding the solution with maximal benefit (fitness). Firstly, due to the population-oriented approach, there is a high likelihood that the optimal design (ideal solution) is searched within a given maximal solution mixing area. Secondly, the gradual convergence of genetic codes of solutions minimizes the risk of finding a second- or third-best-solution within population.

Both facts lead to the following empirical pattern: The fitness value of population increases *endogenously* like a "S-curve" (see Figure 2). Strictly speaking, the average fitness of the population is increasing exponentially during n iterations of IESRM-cycle without exterior intervention, solely based on the continuous application of the evolutionary problem solving cycle. At the same time, *random,* systemic (technology) jumps are possible due to the occurrence of mutations of the genetic code and/ or the intentional extension of product-DNA. In the long run, this will lead to another "S-curve" starting on a higher fitness/ performance level. For example, in the case of brush optimization an extension of product-DNA become suitable in order to represent additional components, such as two different hair materials that are used for the different types of dirt particles.

Conclusion

The application of problem solving cycles, which are based on a model of natural evolution is an interesting alternative to the known relevant Six Sigma process models, such as DMAIC or DMADV. From a scientific perspective, the IESRM-cycle is a specific five-phase-approach inspired by Genetic Algorithms which are used in mathematical optimization models. The IESRM-cycle transfers the biological principle of “adaptation of organisms to their environment” to the R&D problem of “adapting product solutions to customer requirements”.

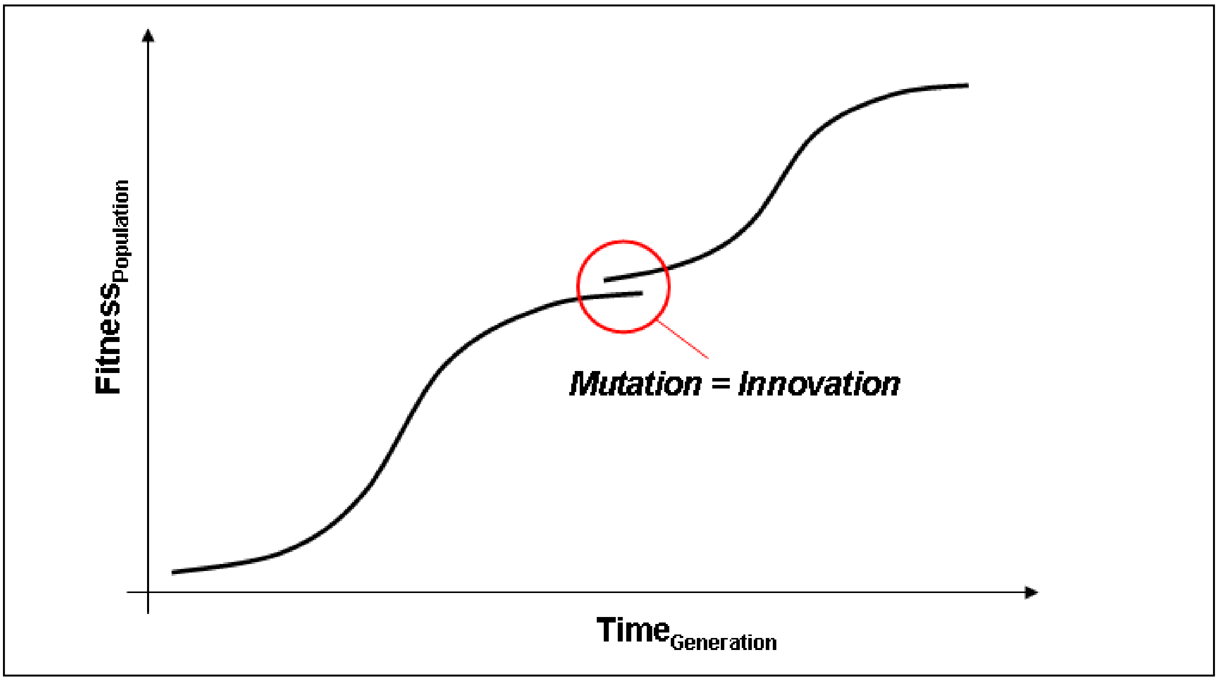

Figure 2: The increase of fitness over time

First empirical studies show great promise both for scientific research and industrial environment. Apart from the high degree of target achievement (effectiveness) the IESRM-cycle ensures a simple operation and handling (efficiency). Particularly, *no* (prior) knowledge of cause-and-effect-relationships of the considered variables is required for a successful application. Since standard quality and/ or innovation tools are used, the training effort to introduce the new cycle to companies is minor. Additionally, the demand on IT-/ Software-support is comparatively low since the whole process can be visualized by a simple Excel tool.

References

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Free Download of Excel-Tool to perform IESRM-cycle: http://www.gabler.de/Privatkunden/Zusatzmaterial/978-3-8349-2507-7/Design-for-Six-Sigma.html.

Author

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