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Computer Aided Design Solution Based on Genetic Algorithms for FMEA and Control Plan in Automotive Industry

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***Abstract*—**In this paper we propose a computer-aided solution with Genetic Algorithms in order to reduce the drafting of reports: FMEA analysis and Control Plan required in the manufacture of the product launch and improved knowledge development teams for future projects. The solution allows to the design team to introduce data entry required to FMEA. The actual analysis is performed using Genetic Algorithms to find optimum between RPN risk factor and cost of production. A feature of Genetic Algorithms is that they are used as a means of finding solutions for multi criteria optimization problems. In our case, along with three specific FMEA risk factors is considered and reduce production cost. Analysis tool will generate final reports for all FMEA processes. The data obtained in FMEA reports are automatically integrated with other entered parameters in Control Plan. Implementation of the solution is in the form of an application running in an intranet on two servers: one containing analysis and plan generation engine and the other containing the database where the initial parameters and results are stored. The results can then be used as starting solutions in the synthesis of other projects. The solution was applied to welding processes, laser cutting and bending to manufacture chassis for buses. Advantages of the solution are efficient elaboration of documents in the current project by automatically generating reports FMEA and Control Plan using multiple criteria optimization of production and build a solid knowledge base for future projects. The solution which we propose is a cheap alternative to other solutions on the market using Open Source tools in implementation.

***Keywords*—**Automotive industry, control plan, FMEA.

I. Introduction

THE automotive industry is one of the most important industries in the world that concerns not only the economy, but also the world culture. In the present financial and economic context, this field faces new challenges posed by the current crisis, companies must maintain product quality, deliver on time and at a competitive price in order to achieve customer satisfaction. Two of the most recommended techniques of quality management by specific standards of the automotive industry, in the product development, are Failure Mode and Effects Analysis (FMEA) and Control Plan. FMEA is a methodology for risk management and quality improvement aimed at identifying potential causes of failure of products and processes, their quantification by risk assessment, ranking of the problems identified according to their importance, to the determination and implementation of corrective actions related. The companies use Control Plans realized using the results from FMEA to evaluate a process or product for strengths and weaknesses and to prevent problems before they occur. The Control Plans represent written descriptions of the systems used to control and minimize product and process variation. In addition Control Plans specify the process monitoring and control methods (for example Special Controls) used to control Special Characteristics.

Presently, the automotive industry faces new challenges posed by the current crisis; companies must ensure quality products delivered on time at a competitive price. For this, companies always appeal to various quality assurance programs at the same time ensuring that their suppliers do this. Failure Mode and Effects Analysis (FMEA) and Control Plan are two of the most recommended techniques of quality management by specific standards of the automotive industry, in the product development.

FMEA is a widely used engineering technique for defining, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the customer [1], [18]. The first formal application of the FMEA discipline was an innovation of the aerospace industry in the mid - 1960s. Since then, it has been extensively used as a powerful tool for safety and reliability analysis of products and processes in a wide range of industries particularly, aerospace, nuclear and automotive industries [2]. In the automotive field it was adopted by the Ford Motor Company as a part of its quality program. Nowadays, the FMEA is the subject of many standards and quality management strategies used in the automotive industry, such as the ISO-9000 series, ISO/TS 16949, Advanced Product Quality Planning (APQP), Production Part Approval Process (PPAP) and Six Sigma [3] – [5], [17]. A system, design, process, or service may usually have multiple failure modes or causes and effects. In this situation, each failure mode or cause needs to be assessed and prioritized in terms of their risks so that highly risky (or most dangerous) failure modes can be corrected with top priority. The traditional FMEA determines the risk priorities of failure

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modes through the risk priority number (RPN), which is the product of the occurrence (O), severity (S) and detection (D) of a failure. That is RPN = O × S × D, where S represents the severity of the failure, O represents the probability of the failure occurrence, and D represents the probability of the failure being detected [3]. The severity, occurrence and detection factors are individually rated using the 10-point scale. However, there are some shortcomings of the conventional RPN method, such as: the RPN elements have many duplicate numbers; the same RPN can be obtained from different combinations of severity, occurrence, and detection. Although the same RPN is obtained, the risk can be different and the relative importance of three risk factors (O, S and D) is not taken into account. In other words, the three risk factors are given of equal importance, but this may not be the case in practice [10], [11], [15]. To overcome the above drawbacks, a number of approaches have been suggested in the literature: fuzzy logic, grey theory, Dempster – Shafer theory, Monte Carlo simulation Genetic Algorithms [7]-[9], [12], [13]–[15].

Control Plans realized using the results from FMEA are utilized in automotive industry to evaluate a process or product for strengths and weaknesses and to prevent problems before they occur. The control plan must [4]-[6]:

- list the controls used for manufacturing process control,
- include methods for monitoring of control exercised over special characteristics defined by both the customer and the organization
- include the customer required information, if any and,
- initiate the specified reaction plan when the process becomes unstable or not statistically capable. By using a control plan together with a dynamic FMEA one can identify potential process failures before they occur, so the process engineer will be allowed to take proactive action to a much lower cost and ensure continuous improvement of the process.

The objective of the work presented in this paper is to show a method to improve the FMEA analysis generation and the control plan in order to increase its generation speed rate and to improve its quality through the computer-aided generation.

Thus, alongside specialist knowledge and experience (which is still an important factor) similar or related experiences history and even other information are considered which specialists could not have - here we refer to the economical aspect of the production process through a cost analysis.

This paper brings two important contributions in this field, which we also consider new elements:

- using an intelligent algorithm for solving a multi-criteria optimization problem (we are talking here about the genetic algorithm) to improve the quality of analysis
- implementation of a complete computer-assisted solution for a faster automated generation of FMEA analysis and the control plan for increasing the efficiency of the production flow.

The two aspects will be described below in Sections III, IV. The paper finally has a conclusion and future trends.

II. Optimization of Risk Analysis Using Genetic Algorithm

The first challenge in the computer-aided generation of the two documents is related to the generation of risk analysis.

The solution we propose is a semi-automatic one. Thus, the team of specialists determines the starting conditions. Furthermore, the genetic algorithm, an artificial evolutionary process of the starting solutions to the desired optimal solutions pursuing an aim will generate an analysis taking into account, along with the starting conditions and situations that have occurred in the similar production processes during time and a financial plan.

Solving an optimization problem considering the criteria as a process failure factor, the cost of the processor and of the means of avoiding defects as well as the factors cumulated from the previous similar production processes with the current one is a very difficult goal to achieve, if not impossible through conventional work methods. Instead it is a typical optimization problem for the genetic algorithms.

Genetic algorithms are a class of intelligent algorithms that are used for solving the multi-criteria optimization problems [16]. Like other artificial intelligence algorithms, GA are used where solutions by conventional, deterministic search methods are hard to find. This is because intelligent algorithms use pseudo-heuristic search methods: they combine the heuristic method with the deterministic one.

Genetic algorithms use genetic evolution in biology as a model. It starts from a set of initial solutions. An encoded solution is called chromosome or individual. These algorithms do not work with one possible solution but with a set of solutions that will evolve. All of the solutions at one time is called generation and the solutions obtained during several generations are called population. Thus, we are talking about a population of chromosomes (solutions) evolution from one generation obtained almost randomly - possibly considering certain limits – called the 0 generation at the last generation containing the solutions sought.

The process of evolution is shown in Fig. 1.

The evolution of the population of solutions is carried out by applying some operations that simulate the biological model after which they have inspired. Thus, after evaluation, that is a process in which solutions are tested to see if they approached the desired purpose, the selection of the "most gifted" individuals occurs. Usually, the selection method is one that contains a heuristic and an elitist part. The method is called "the roulette method" - in which every individual in the population has a chance to participate in the reproduction process - off-spring generation - but the individuals which have achieved the best results in the evaluation are favored (i.e., those closest to the desired solutions, which best meet the required purpose).

The selected individuals (called parents) participate in the crossover operations. The artificial crossing model is also a pseudo-heuristic method for randomly establishing the crossover point and then the genetic information is exchanged between the two parents. As a result there will be a follower that has information from both parents in the chromosomal structure. Hypothetically (if you follow the natural model) over several generations followers have to be more evolved than their parents in the sense that in the evaluation process they will be subjected to they will achieve better results – they are closer to the sought solutions.

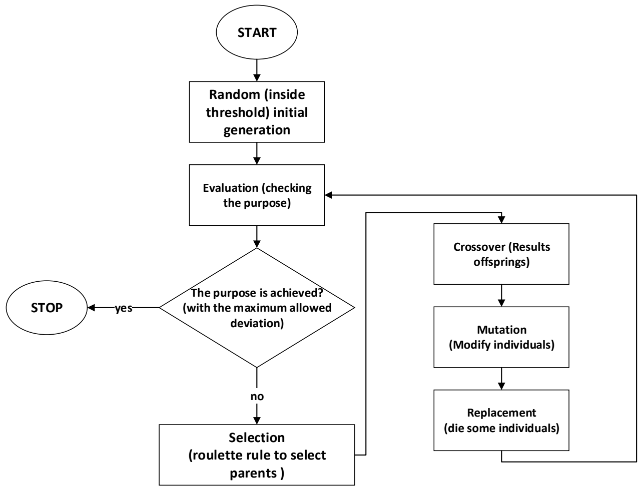

Fig. 1 Flowchart of genetic algorithm (GA): In our case, initial generation is obtained using threshold for failure mode factors introduced by specialist team and values from similar previous production processes from data base

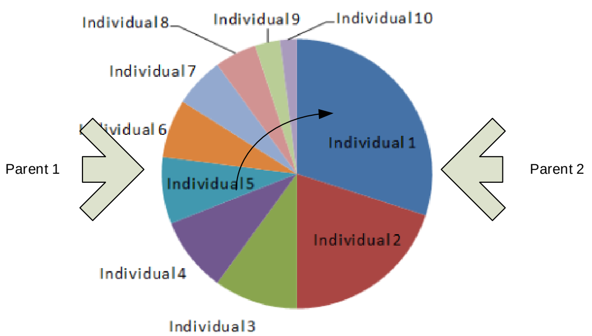

Fig. 2 Selection using roulette rule: Each individual has allocated a surface from roulette wheel proportionally to the result of the evaluation (fitness)

To avoid convergence to a local minimum - a set of solutions that on a region of the search space approaches the optimal but not throughout the whole search space, a genetic operator is also introduced that has a higher degree of randomness for the solutions' dispersion - it is about mutation. This allows the escape from a local minimum. Here, any of the individuals - usually chosen randomly – is also selected on some position in the chromosome – which is also at random - deciding an arbitrary change.

The evolution loop resumes by assessing the new generation composed of individuals from the old generation along with the offspring obtained after crossing and mutation.

Unlike other intelligent algorithms, in which the solutions are known and they are used to get to these solutions (note neural networks or fuzzy algorithms used in a wide range of applications for classification, recognition, pattern extraction etc.) the genetic algorithms are used to search for the initially unknown solutions.

When it comes to the evaluation, a goal is considered, a goal on which we can determine how close the provisional solution is (the individual which is being evaluated) to the solution sought. An example that shows the difference between goal and solution is solving a mathematical equation. The goal here is that the expression on the left side of the equation is 0 (or very close to 0 with a tolerated margin of error). The solution (or solutions) represents the value (s) of x that satisfies the order.

The genetic algorithms can also be used to solve some equations difficult to approach by conventional methods.

There are several papers in the risk analysis field that have proposed to improve the analysis process using intelligent algorithms: fuzzy and neural networks.

The solution we propose uses the genetic algorithm. The problem is to minimize the risk of failure by using the result obtained in similar past experiences and by using of some parameters resulting from the financial cost analysis of the inclusive production process with the implementation of means to avoid defects.

Such a problem, impossible to solve by conventional means can be solved by using genetic algorithms.

The first challenge is to encode solutions as chromosomes (individuals) in the population. The chosen solution is illustrated in Fig. 3: A chromosome is composed of several gene – in our case, a gene represents the three risk factors for a failure mode. The chromosome represents all the failure modes.

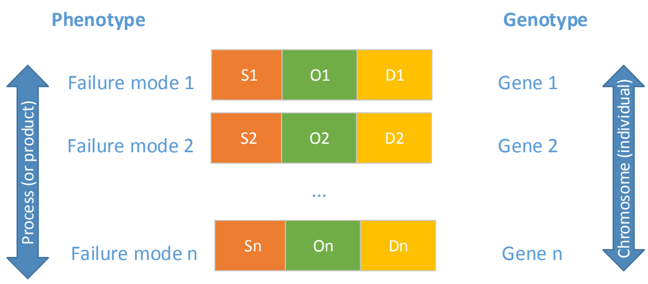

Fig. 3 Coding schema used in our paper work: The failure modes for the process represent the chromosome (or individual) while a failure mode (with three factors) represent a gene in chromosome

Genetic algorithm parameters are chosen empirically depending on how it is established that evolution takes place. They are: the number of individuals per generation, the number of parents' pairs (crossing rate), the number of crossings, mutation rate and the method of substitution.

Table I shows the parameters AG used in this work paper.

The process of evolution is monitored continuously the status of individuals per generation is read and stored in a file.

As an interesting observation, the set of individuals (potential solutions) evolve from different solutions to the optimal solution. Finally, the genetic heritage for all individuals is similar in our case – so we have many solutions but similar as values.

TABLE I
PARAMETERS OF GENETIC ALGORITHM (GA) USED IN OUR PROJECT

Parameter	Value
Number of individuals / generation	10
Maximum of generations	500
Selection method	Roulette
Pair number (crossover ratio)	1
Crossover points	1
Selection method for mutation	Random
Mutation ratio	0.3
Evaluation function	Cost minimization
Selection of replaced individual	Elitist (the poorest is replaced)

An optimal solution is a complete analysis FMEA for a production process that takes into account both the possible failure modes that can occur and the cost required to prevent failures.

III. COMPUTER-AIDED SYSTEM FOR GENERATING CONTROL PLAN AND FMEA ANALYSIS HELPFUL HINTS

The above algorithm is integrated into a computerized system that can generate the final FMEA analysis and data for control plan.

A block diagram of the final application is shown in Fig. 4.

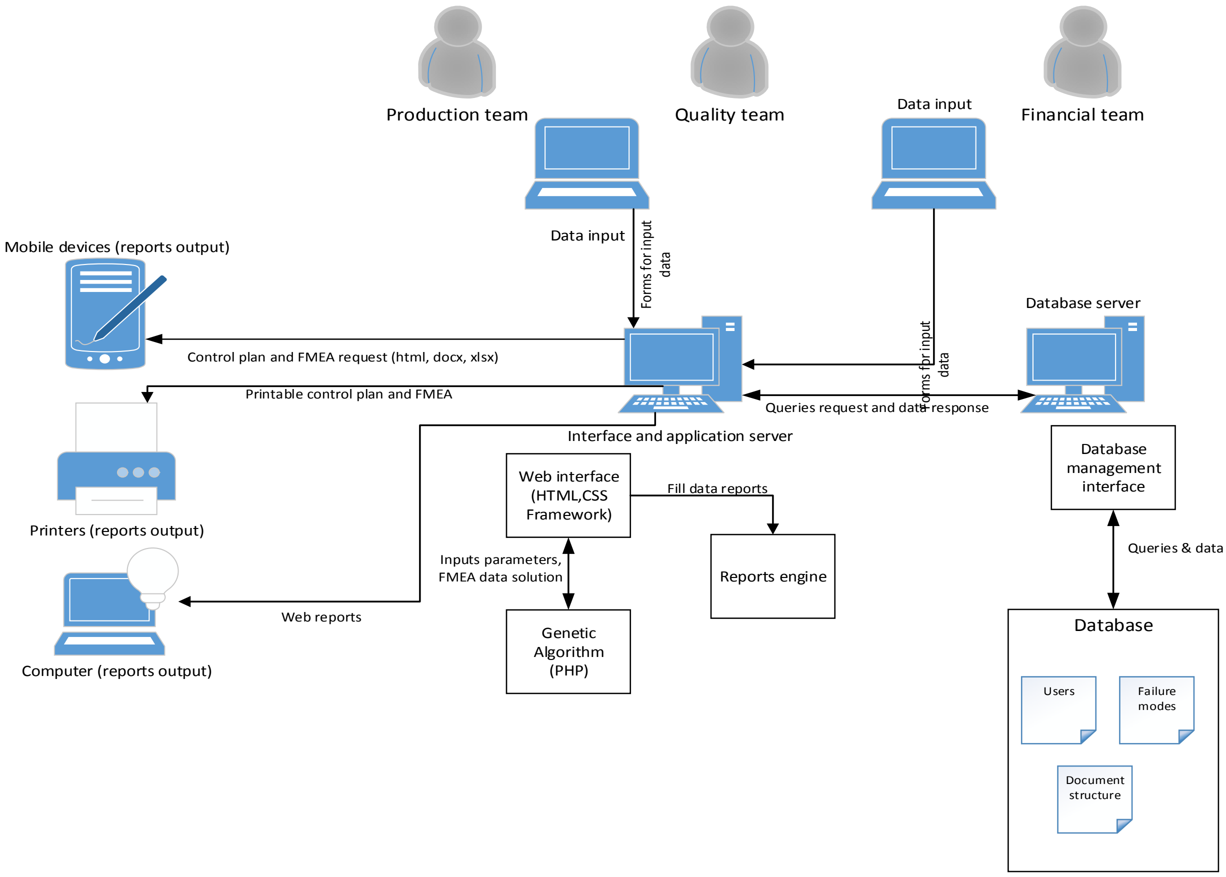

Fig. 4 Block diagram of the application: to Interface and application server run web interface (forms), genetic algorithm for FMEA generation and reports engine. Data introduced by the users and results from AG are stored in data base and for AG and reports generation are used data from DB. DB contains three tables

The algorithm is integrated in an intranet application that is available for many categories of users:

- Project manager ensure coordination and monitoring of the entire document generation process (including FMEA and control plan);
- Quality specialist;
- Specialists in maintenance;
- Specialists in manufacturing.

As can be seen in Fig. 4, the application is designed to be organized in two servers: HTTP server that is running the applications itself - responsible for generating, using the evolution, the risk analysis and other documents and database server where are stored data for a specific production process for further use and other parameters entered by the design team.

The application contains an interface with users; each user has his or her specific access. Thus, each member of the design team can enter its specific data. After running intelligent algorithms is necessary to generate reports in formats accessible to the customer.

In practice there are different solutions for document management in an enterprise: business solutions among which mention package from Microsoft SharePoint and Open Source solutions such as Alfresco. However, these solutions show a degree of generality that sometimes make them inaccessible to users. Instead our solution is a solution dedicated to industrial environment and is centered on the production processes in the automotive environment. This is a special element of originality in our work paper. And of course, the novelty is made using intelligent algorithms (genetic algorithm) for generating document types - we refer to risk analysis document.

As technologies used to build the application went on Open Source: PHP, MySQL database, Apache server, framework html / css "Bootstrap" and "Kickstart" and for generating reports in excel / and word documents: PHP library ThinyButStrong.

As a result of computer aided document generation are actual reports constituting the control plan and FMEA analysis. Fig. 5 shows the steps for generating the documents.

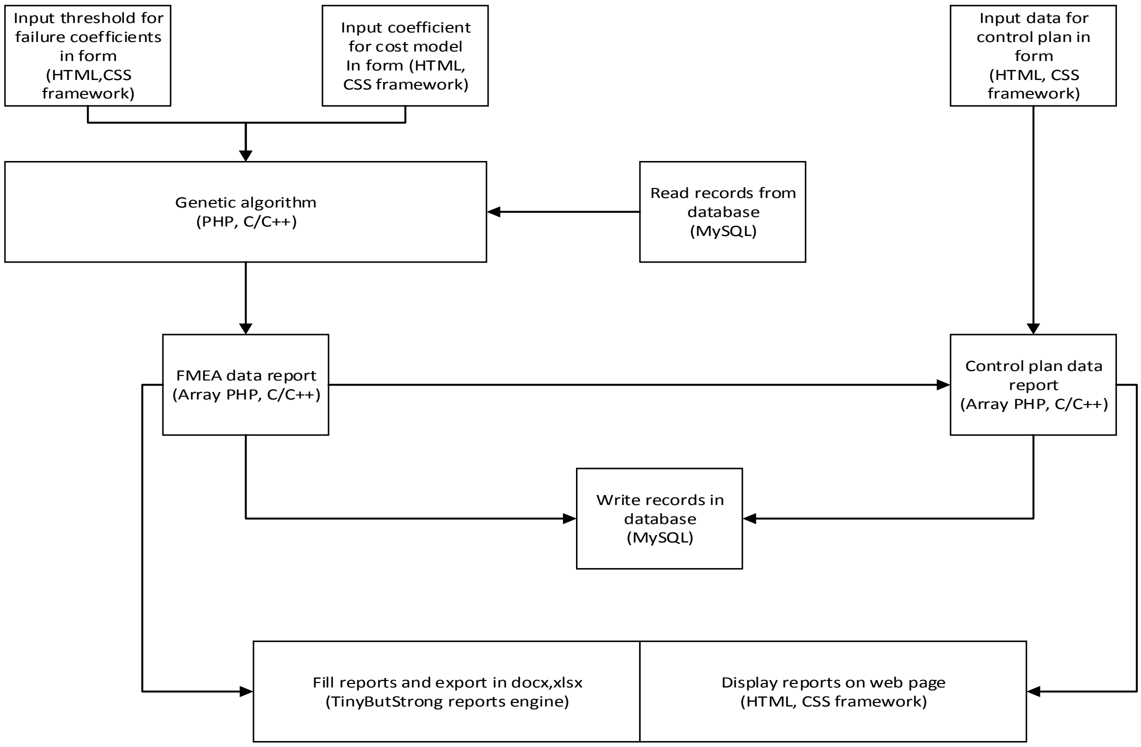

Fig. 5 Flowchart of application: data are introduced by the users for FMEA and control plan in web forms, GA use input data and data from DB, results from GA are stored in DB and send to control plan module and report engine. Control plan use data from FMEA and input data. The reports can be displayed on web interface or exported in documents

By intranet solution for generating and managing documents is allowed collaboration between teams working in different branches of a company or even in different areas - for international corporations.

The application was tested in an automotive company to obtain reports FMEA and control plan in the manufacture process of a chassis. Document generation time has been reduced significantly compared to conventional methods and FMEA solution obtained allowed reducing non-quality costs.

IV. Conclusion

The innovations and originality that brings the work are:

– Use of intelligent algorithms for risk assessment - genetic algorithm for risk analysis - taking into account several factors in the production process cannot be correlated with each other by conventional methods (along with technical factors to take into account the financial aspect or experience);
– A computer-aided solution dedicated for automotive production environment for generating and managing reports;
– An intranet environment for development teams working on the project;
– Automatic generation of reports in accordance with the quality standards;
– Open source solution.
– Compared to existing solutions on the market or in research, our solution brings the following improvements:
– Risk analysis reports can estimate failure rates and optimal maintenance costs;
– Significant decrease in report generation time;
– Available on the intranet which increases the connectivity between design teams.
– The low cost of the solution.

The intelligent algorithm occurs only to generate risk analysis. At the other document (control plan) to the imported data from the FMEA report went on conventional methods of synthesis of other date- through graphical interfaces with forms - while remaining computerized support and automatic generation of report. As research direction would be the possibility of extending the use of intelligent algorithms (genetic where necessary optimal solutions or neural network where needed classification) and generating other types of reports as we did in risk analysis.

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