DESIGN AND OPTIMIZATION APPROACHES TO PROVIDE A FRAME FOR DESIGNER IN THE VEHICLE DEVELOPMENT PHASE WITH THE FOCUS ON ENHANCED SAFETY

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ABSTRACT

The safety of a vehicle is today of great importance for the automotive industry. The light weight vehicle designs are to increase in worldwide over the next years with respect to environmental and road safety regulations to make surface transport safer and more effective. The vehicle design models are usually complex in nature and nonlinear in terms of computational issues. The design and optimization in the area of transport are usually challenging tasks due to the highly nonlinear behaviour of structural parts with respect to durability, crashworthiness and vehicle dynamics issues. The design optimization process is usually limited by the excessive costly computational requirements in case of nonlinear model simulations and with respect to the difficulties for efficient exploration of multi-objective design space in the area of vehicle safety research such as crashworthiness. Although some studies which are given in literature have been carried out to solve the safety problems such as crashworthiness, they have not been efficiently solved yet. Recently, significant research in the area of vehicle safety and light weight vehicles through simulation based optimization undertaken, and it is expected to continue further resulting in reductions in cost and time for new vehicle development process. The purpose of this paper is to explore design optimization approaches for development of light weight cars to satisfy safety needs for automotive structure and its components. In this paper, the shortcomings of traditional approaches, new design optimization approaches, stochastic and intelligent approaches that can be implemented to handle complex and nonlinear models are presented to provide a frame for designer in the vehicle development phase with the focus on enhanced safety for lightweight vehicles in the automotive industry.

INTRODUCTION

The number of safety and light weight vehicle regulations has been presented to improve safety and quality of road transport. The regulations will continue to increase in over the next years. This will have increase environmental and road safety issues worldwide with respect to making surface transport safer, more effective, and more competitive. The automotive industry must present new approaches especially in the automotive design process to produce new products, which are least sensitive to disturbing factors of manufacturing and environment issues with the focus to safety and lightweight.

Road transport safety has improved significantly over the last decades as indicated by a 50% reduction of the total number of fatalities in the EU. This decrease is with respect to continue as new safety regulations and technologies and through improved passive and active safety systems, but with increased mobility the current situation with 43,000 deaths and 1.9 million injured on European roads requires further efforts. A target of halving the number of fatalities on European roads by 2010 has been set (as compared to 2001), and further reduction is reported for 75% by 2020. Therefore, further research on enhanced safety concepts should be carried out in order to achieve these targets [1-6].

It is obvious that a significant improvement in vehicle safety will depend upon the presentation of innovation and advanced design optimization techniques. In addition, a substantial reduction of accident fatalities can be achieved through an integrated system design and optimization

approaches considering both vehicle technology and infrastructure.
The purpose of this paper is to explore design optimization approaches for development of vehicles to satisfy enhanced safety needs for automotive structure and its components. The design optimization approaches with less computational efforts, stochastic optimization and intelligent approaches are presented with the focus on enhanced safety applications especially with respect to crashworthiness and optimum design of vehicle systems and components.
This paper is organized as follows: vehicle safety R&D aspects are taken into account in "Vehicle Safety R&D" Section. It is based on current situation, roadmaps and future research directions referencing automotive related organizations and papers published in literature by academis and industry. The optimization techniques with reference to vehicle safety are outlined through stochastic techniques and simulation approaches in "Optimization Techniques in Vehicle Safety R&D" Section. Finally, "Conclusions" Section is included to summarize vehicle safety R&D and design optimization issues to design safer vehicles in the automotive industry.

VEHICLE SAFETY R&D

Safety aspects and mobility are growing concerns in both developed and developing countries. The safety of a vehicle and road transport is today of great importance and a high priority research area for the automotive industry.
The reduction in road accident fatalities and injuries can only be achieved by introduction of improved technologies for newer vehicles and road transport systems regarding vehicle safety standards. Therefore, further research on enhanced safety concepts must be carried out in order to reduce the accident fatalities and to achieve better occupant protection on road transport. In addition, the cost reduction to present safer vehicle designs through shorter lead times must be satisfied by introducing new optimization approaches.
Although significant improvements have been achieved to meet the safety needs of society and industry, there is an increasing demand to further increase passive and active safety systems.

There is a need to define the road maps and strategies for future research areas to achieve given targets and overcome the limitations of existing systems. This will help to reach the social and industrial needs in more effective and cost efficient way and it will prevent independent works with the lack of common position on the issues of vehicle safety and road transport. In this section, vehicle safety R&D is investigated regarding papers published by academia and industry in literatre and also from the side of automotive related organizations.
The automotive related organizations are established to bring together independent companies and R&D providers belonging to industry, private and public research institutes and universities to enhance vehicle safety and other automotive related issues in the automotive sector throughout Europe [1-6]. For example, EARPA is the association of automotive R&D organizations. EARPA-AVDT presents the safety aspects to introduce the future safer vehicles and to introduce new technologies for safe and secure road transport systems. ERTRAC is a technology platform. ERTRAC's goal is to provide a framework to focus co-ordination efforts of public and private resources on the necessary research activities in the vehicle development area. Safety issues are also covered by APROSYS, APSN, FURORE organizations. APROSYS Integrated Project (IP) deals with the development and introduction of critical technologies that improve vehicle safety for all European road users in all relevant accident types. Another organization regarding safety issues is APSN (Advanced Passive Safety Network). It is established to promote passive safety research and to help in the dissemination of information and results, all with a view to reducing the number of casualties on European roads. The APSN is aimed at providing prioritised future vehicle safety research needs and actions. FURORE is a thematic network platform to discuss breakthrough technologies and the corresponding research demand for the future vehicles. EUCAR developed an Automotive R&TD Master Plan in order to define a European approach to technologies for automotive development and to present the major R&D challenges the automotive industry is facing. The CARS 21 final report reflects the deliberations, opinions and agreements within the CARS 21 High

Level Group, which was set up to chart the way towards sustainable development of a competitive European automotive industry. In CARS21 final report, it is stated that a holistic, integrated approach involving vehicle technology, infrastructure and the road user is the best means for increasing road safety and a crucial point is due to R&D investments to improve the current levels on road transport with particular relevance to safety and security [2].
Research field descriptions and road maps regarding vehicle safety and road transport are defined by these organizations in details bringing together Universities, R&D organizations and automotive sector representatives.
Vehicle safety R&D is becoming one of the important research area through the design of enhanced safety components using new optimization techniques and intelligent systems. Research targets and road maps show that the significant enhancement in vehicle technologies and safety is crucial for future vehicle design concepts to satisfy social and industrial needs. It can be concluded that the reduction in accident fatalities and injuries can be achieved through introduction of new design optimization approaches, intelligent systems and innovation to produce safer vehicles with new structures and safety aspects.
Recently, several papers have been published in literature with respect to vehicle safety especially about crashworthiness and structures [7-18]. The most common point is that the implementation of multi-objective optimization methods through stochastic techniques are required to design enhanced safety vehicle structures and systems to handle with uncertainty and variability and able to explore pareto optimal design space for global optimization. Multidisciplinary simulation and multi objective optimization methodologies, techniques for handling uncertainty and variability to design are reported to support the design and optimize the vehicle components of future advanced safer vehicles, for example, the development of new methods, that will guide protective safety design for the improvement of safety in case of crashworthiness of cars in frontal and side impacts through global optimization approaches.

OPTIMIZATION TECHNIQUES IN VEHICLE SAFETY R&D

The automotive industry must present new approaches especially in the automotive design process to produce newer models with the focus to enhanced vehicle safety issues through lightweight products, which are least sensitive to disturbing factors of manufacturing and environment to make surface transport safer, more effective and competitive. In this section, the optimization techniques which are implemented in vehicle development process are introduced referencing to vehicle safety aspects, especially crashworthiness and vehicle structures.
The design and optimization in the vehicle development process regarding safety aspects such as crashworthiness are usually challenging tasks due to complex models and highly nonlinear behaviour of vehicle structure with respect to durability, fatigue and vehicle dynamics. The design optimization process is usually limited by the excessive costly computational requirements in case of nonlinear model simulations and with respect to the difficulties for efficient exploration of multi-objective design space. For vehicle safety problems, such as crashworthiness, the responses are often includes uncertainties and it has several drawbacks that can cause numerical difficulties to find search direction through time consuming approaches and in some applications, it may not even be possible to compute the derivatives
Although some studies which are given in literature have been carried out to solve the crashworthiness problem, the problem has not been efficiently solved yet [7-18].The crashworthiness design and optimization are challenging tasks due to the highly nonlinear behaviour of a structure. Therefore gradient based approaches such as steepest descent, conjugate gradient, Newton methods are hard and expensive to find the search directions and also explore design space. In these techniques, the search direction is computed at an initial estimate for the minimum design. The initial point definition for estimation of a starting design may cause drawbacks with respect to convergence rate and even to stick in infeasible solution areas [19-21].
In traditional approach, complexity of design models can cause limitations due to analysis,

optimization and simulation process requirements of vehicle structures.

The structural layout, which is defined by initial design concept, and shape optimization have significant effect on product performance and manufacturing cost. Therefore, how to achieve optimal initial design concept and how to achieve efficient shape optimization process are important issues which took significant attention by researchers in recent years. Initial design concept is often based on experience of designers and it includes uncertainties which may cause unexpected shortcomings during the development phase and the life of the product. These shortcomings of traditional design approaches can be handled by defining stochastic optimization techniques with topology design approach [22]. Topology design approach is widely used to define initial conceptual structural layout of products. It provides an initial design concept for downstream applications following design. In traditional approach the starting design outlines are not optimal therefore further optimization works on the structure will not be the right solutions. Topology optimization searches for the best conceptual structural layout on a predefined design domain with specific boundary and loading conditions to achieve optimal initial design structure.

Another problem in automotive industry is how to achieve Safer vehicle design concepts by considering structure performance and manufacturing cost in the early stages of product development. The optimisation methods are used to design products, which are light-weight to improve the cost and fuel efficiency, without sacrificing strength and performance due to safety requirements. During the optimisation, the shape and size of structure can be changed, but the topology of the structure is not changed. Therefore, optimisation techniques have to be considered in the conceptual design phase to create an optimal initial design layout.

Recently, topology design, artificial intelligence and stochastic optimization techniques are widely implemented to design optimization problems in vehicle safety and road transport areas. The shortcomings of traditional approaches in vehicle design can be handled by defining the optimal topology as initial design concept and by using artificial intelligence techniques and stochastic optimization approaches such that uncertainties can be prevented with less computational efforts.

Most real world engineering problems involve at least an element of uncertainty in loading conditions, in material characteristics, in analysis process, in manufacturing, etc. Many optimization approaches do not consider this uncertainty for the design optimization process. In recent years there is a growing interest in the automotive industry, especially in the design process due to the effectiveness of the stochastic optimization and artificial intelligence techniques for improving the quality characteristics of the products and to overcome the above mentioned shortcomings [19-21].

Stochastic optimization does not have above mentioned drawbacks with respect to search direction and exploration of design space which are important aspects in case of multi-objective vehicle safety cases. Widely used stochastic design optimization techniques are Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA). In stochastic optimization different background variables can vary stochastically during the optimization procedure. A major difference between stochastic optimization and traditional optimization methods is that stochastic optimization is rather a reproduction of the real model considering uncertainties.

Modelling and simulation techniques are also implemented in optimization algorithms to enhance the presentation of solution space, to reduce the number of experiments and to analyse sensitivity of design parameters such as Response Surface Method (RSM), Design of Experiments (DO), Taguchi Method (TM) [17-19]. For crash simulation problems with a highly non-linear behaviour of the objective function, the use of local gradient based optimization algorithms is not suitable. volutionary algorithms are more efficient for these problems.

Artificial intelligence techniques are also used to define design optimization models in case of uncertainties. Neural network, also called artificial neural system, is an information processing technique which is developed to simulate the functions of a human brain. Neural network is composed of elementary processing units which are called as neurons. Neurons are interconnected

by weighted connections. Among various neural network architectures, back propagation (BP) is a widely used technique for training of multi layer perceptrons (MLP). An identical process is repeated for each weight of the hidden layer connections if there is more than one hidden layer. Several repeated solutions with different initial weights and network parameters are used to converge to the optimal solution [20].

The real world design and manufacturing problems are usually multi-objective, often conflicting, and they have uncontrollable variations in their design parameters with complex nature. The objectives must be satisfied simultaneously in order to obtain an optimal robust solution. The whole problem must be taken as multi-objective with the Pareto optimal set instead of single objective optimization. Traditional optimization methods are not only time consuming in solving complex nature problems that include multivariable and multi-objective but also they may not be used efficiently in finding global or near global optimum solutions. In addition, they can stick to the local optimum values such as in case of crashworthiness problems.

Traditional design procedure is an iterative process. It starts with an initial concept design that is based on the experience, knowledge and intuition of the designer. Analysis and redesign steps are carried out to evaluate and modify the product layout. This is time consuming and inefficient procedure that can create sub-optimal structure layouts since starting topology is not optimal. The designer may consider many alternative topologies and one of them is chosen as being final component layout. This procedure may result with final component layout, which is often non-optimal. However, in topology optimisation approach, designer does not have to choose optimal topology among alternatives and no priori knowledge about topology is required. The goal of topology optimisation is to find the best use of material for a component [23].

CONCLUSIONS

In this paper, design optimization techniques are outlined with reference to enhanced vehicle safety research to support more sustainable transport development. It is shown that stochastic optimization and intelligent approaches can be implemented to handle complex and nonlinear design models to provide a frame for designer in the vehicle development phase with the focus on enhanced safety in the automotive industry. In general, conclusions can be given as follows:

- There is a need to develop computationally efficient techniques to design competitive products for safer vehicle structures by increasing transport safety in line with the objectives for European transport policy in order to reduce the annual road victims.
- There is a need to consider uncertainties in crashworthiness using stochastic optimization techniques to achieve efficient designs, for dynamic problems, without considering uncertainties may cause infeasible solutions.
- There is a need to develop design frames to be employed at early design stages since the problem is due to initial design, which highly depends on experience and skill of designer, this can cause inefficient design alternatives which are not optimal.

Although some studies which are given in literature have been carried out to solve the safety problems such as crashworthiness problem, the problem has not been efficiently solved yet. Further research is essential to improve the vehicle safety and road transport systems through the use of advanced optimization techniques and innovation. This will help to reduce the casualties on road transport to the lowest limits and to achieve the targets set related to road transport safety.

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