Product Design and Development through Numerical Simulation Technology: Sri Lanka Perspective

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Introduction

The global society as at now is at the pinnacle of development in many different fields including science, engineering and technology. However the ambitious nature of the human being has never been fulfilled though they have been able to send satellites to stars, thousands of miles away from the earth. Aforementioned statement depicts, we have been able to explore the *macro and mega* scale of the universe in parallel with never ending cycles of design / development of machineries and equipments. Jumbo jets, space rockets / shuttles and satellites portray the apex in this scale. Besides, man has never introduced barriers to explore micro / nano, and even quantum level of the matter, extended the technology of the equipments and machineries to scrutinize the miniature world. The motivation in this has probably triggered due to the need to alleviate human/animal diseases in medical and biological sciences through the development of micro/ nano imaging. Later, the trend shifted towards in the development of miniaturized machines, novel materials through the introduction of Electron / Scanning Electron Microscope. Though the development has widened bi-directionally (towards mega and pico level) in size scale, human thirst in exploration of nature will never be quenched.

In this journey of experimentation, application of computers has always been a key factor in the advancement of science and technology. Though the contribution of computers in various aspects is widely known within global community, a question still remains whether the general public with science background, operational level managers in industries and some academics in certain universities in Sri Lanka are aware of this regard. In Sri Lanka, the affiliation of computers in science and engineering is always broadly referred to as *Computer Aided Design and Drafting* or *CADD*. Nevertheless there are other alternatives that this can be used in a much broader sense. The country has appealed to various investors of different leading industries (semiconductor, automotive, aerospace and materials processing) that it is vital to become aware of

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this regard. The aim of this article is to make the readers aware on the other alternatives in using computers, so that Sri Lanka can utilize this in the growth of her economy in a much broader sense, in engineering design and development.

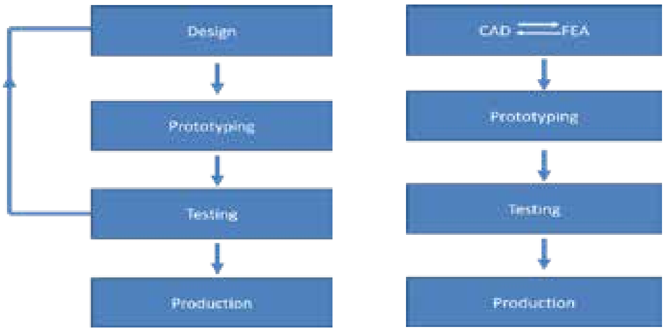
Engineers and scientists have been playing the most important roles along this long journey and they mainly involve in modeling of physical phenomenon in nature. Engineering and scientific modeling is essential in predicting the outcome of certain phenomenon that is useful to human existence, such as finding concentration of pollutants in lakes and sea water, prediction of the weather in an attempt to understand the formation of thunderstorm and tornadoes, to determine of stress/strain distribution of structures subjected to mechanical, thermal and aerodynamic loads, in countless other engineering applications. These processes and anomalies can be described with the aid of the laws of physics or other fields in terms of algebraic, differential and /or integral equations; that relates variables of interests. Most of these expressions are analytical descriptions of physical phenomena and processes and are called *mathematical models*. The complexity of these mathematical models can range from Newton's second law of motion to Navier – Stokes equations in fluid dynamics. The increased complexity of the solution process itself restrict the scientist or the engineer in achieve their intended task. However, computer technology has enabled an immense relief in this respect with the use of *Numerical Simulation*. The main intend of this article is to aware the readers on the impact of numerical simulation on the technology and improvement of product life cycle.

Numerical Simulation

The use of numerical method and a computer to evaluate the mathematical model of a process and estimate its characteristics is called *Numerical Simulation*. In computer industry jargon, numerical simulation lies in CAE or Computer Aided Engineering domain; is the use of computer software tools to engineering analysis tasks. Numerical Simulation is implemented on systems comprised solely on solids, liquids and systems that have interaction between solid and fluids. Following techniques are used to perform numerical solutions in problems exclusively consisted on

1. Solids – Finite Element Analysis (FEA)
2. Fluids – Computational Fluid Dynamics (CFD)
3. Solid Fluid Interaction – Multi Physics Simulation Techniques.

The influence of these techniques to traditional engineering design has been tremendous since it was evolving around 70s. The article is mainly focused on Finite Element Analysis.



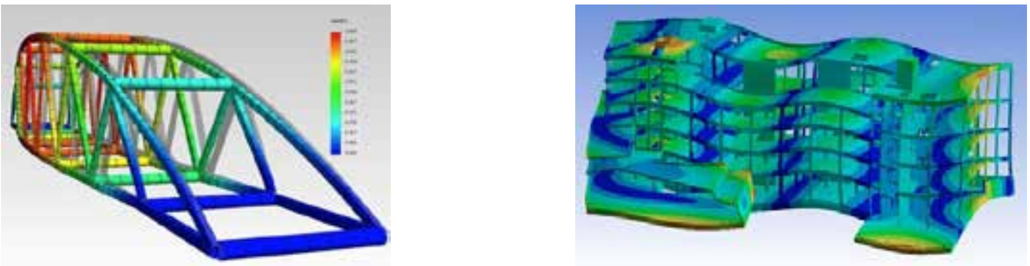
(a) (b)

Figure 1: (a) Traditional driven design process (b) FEA/CFD driven design process

According to figure 1(a) traditional design process consist of an iterative loop between "design" and "testing" stages. It is widely known that engineering design is a repetitive operation and generally incur considerable amount of financial and time commitment to obtain a successful efficient product. The financial and time commitment incurring in this process is mainly due to the construction of physical prototype of the design and validating it with the actual environmental or factory conditions. It is indeed in this step that designer identifies the weak localities of his/her design and requires performing another trial with the modified design. This process need to be done several times and acquire significant amount of time and money.

This can range from petty hundred dollars per days to millions of dollars per year, depending on the scale of the industry. The remedy for this issue lies in numerical simulations. With respect to figure 1(b), it is clear that the recurring loop has departed. The key reason is that once the numerical simulation is introduced, the production of physical prototype will be omitted and instead, the equivalent will be represented by computer aided design (CAD). The numerical simulation will be performed on the CAD model, such that the actual working conditions and the behavior of the material / fluid of the proposed design are described accurately by mathematical model. Hence the need for actual run of the prototype of the design through costly facilities is no longer required. If there is a need of a physical CAD can also be easily modified and promptly rectified based on the requirement of the product performance. This approach can significantly reduce the product development cost and will incur profits. Some of the areas that we can apply the said technology are elucidated by the following figures.

1. Civil Engineering (Building and Structural Engineering Design)



(a) (b)

Figure 2: (a) Bridge Design (b) Building / Structural Engineering

2. Mechanical Engineering (Automobile / Engine related component design)

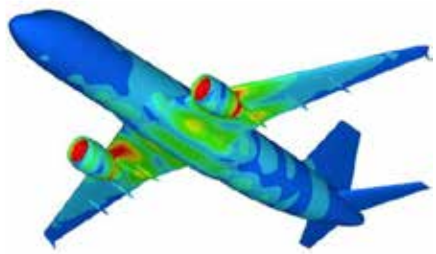


Figure 3: Automobile and engine development

3. Electrical Engineering (Design of electrical machines with the consideration of heat dissipation and electromagnetic flux distribution)

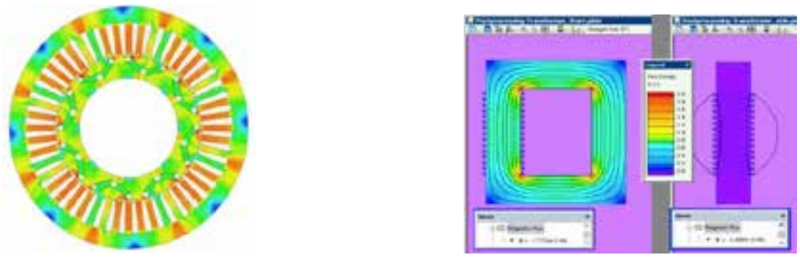
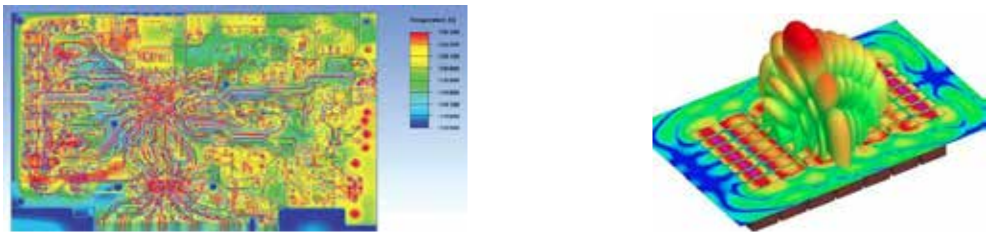


Figure 4: (a) Electrical motor magnetic flux analysis (b) Electrical transformer flux density analysis

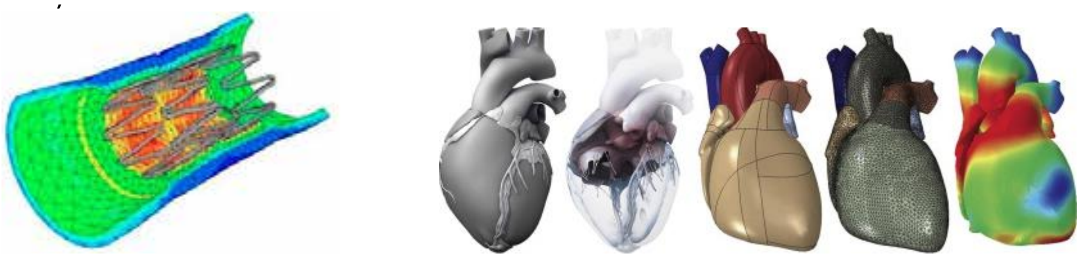
4. Electronic and Telecommunication Engineering (Analyse the heat dissipation of circuit board with the intention of the application of heat sink)



(a) (b)

Figure 5: (a) Electronic circuit temperature analysis (b) Flux density analysis of antennas

5. Bio Medical Engineering (Analyse the stress strain behavior of biological tissues to develop bio materials and to design bio medical and surgical instruments in the medical field)



(a) (b)

Figure 6: (a) Design of Stent geometries for the solution of coronary heart diseases (b) Heart modeling for stress and strain analysis under different conditions.

6. Textile and Clothing Engineering (Analyse stress – strain behavior of technical textiles to be used in aggressive environment to specific purposes)

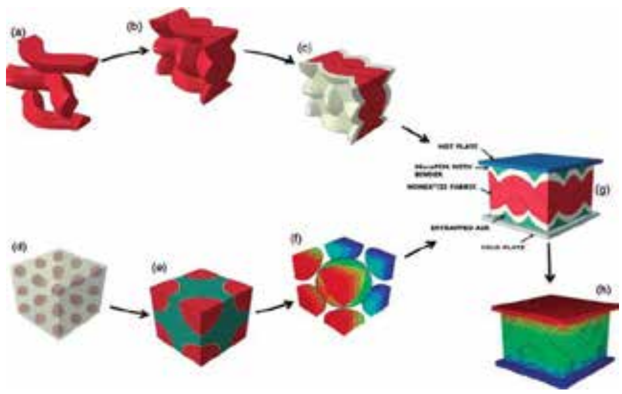


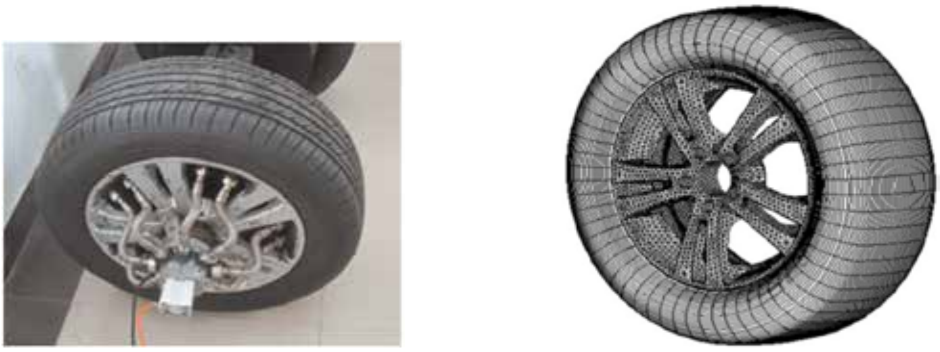
Figure 7: Design of weaving patterns and application of different materials for better performance of the intended textile.

Following are the Benefits of Numerical Solutions.

1. Reduction of the number of prototype used.
2. Reduce design and analysis cycle time.
3. Optimize design for weight or cost.
4. Identification of design errors at initial stage of design.
5. Ability to handle complexity. (Material, Loads, Boundary Conditions)
6. Visualized Stress distribution and deformed shapes of the design.

Finite Element Analysis (FEA)

A rigorous mathematical explanation of FEA is not the intent but a brief introduction on the method. Critical and in-detail explanations are available in various text books available in literature [1], [2]. FEA acts by the method called *Finite Element Method* or *FEM*. In *FEM*, a given solid domain is viewed as a collection of sub domains, and over each sub domain the governing equation is approximated by a traditional mathematical techniques. Product designs with complex shapes are not possible to analyze using traditional analytical frame work. However with FEM, one can subdivide the complex design into simple geometrical domains (squares, triangles) and the numerical method typically transform differential equations that govern the full domain of the design into set of algebraic equations of a discrete model. Following figure illustrate FEA mesh of a vulcanized tire model in studying the performance at different rolling conditions.



(a) (b)

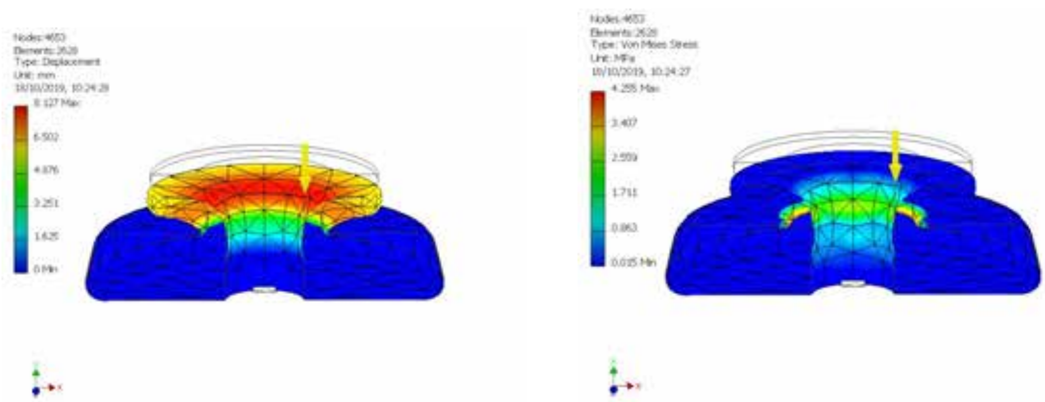
Figure 8: (a) Physical tire to be developed/analyzed (b) FE mesh of the CAD model of the tire [3]

Subsequent to the action of the discretisation, each domain is considered as an individual *element*. Loading or boundary conditions applied to the considered geometry are also distributed along each domain according to a formulation, such that the total effect would be the same. Once the boundary conditions or the loading conditions are determined for each domain; material behavior; contact conditions will be taken into consideration. Once these inputs are satisfied, it is the role of the computer to calculate stiffness of each element of the complete domain. In the event of completion of the elemental level calculation, the computer requires to assemble all the elements that consist the original geometry or model. It is in this process that computer needs to represent the total solution of the complete domain, in order that the analyst can consider the requirement, whether to change the selected material, boundary condition or the original geometry.

A summary of a comprehensive case study, conducted in the Department of Materials Science and Engineering of University of Moratuwa will elucidate the use of FEA in engineering product design. In this scenario, it is a polymer based rubber strut mount design modification.

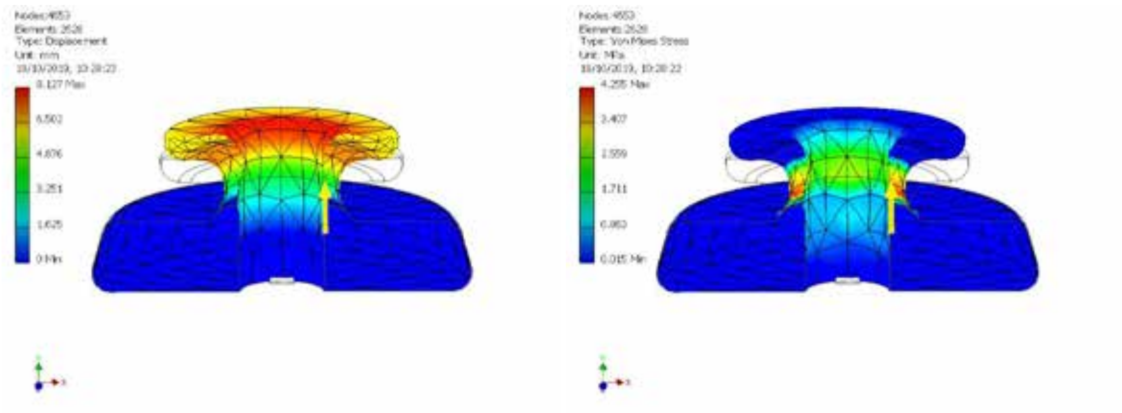
The primary function of a rubber strut mount is to isolate the vibrations transmitted from the wheel to the vehicle body. The rubber component of the strut mount absorbs the vibration energy and dissipates it as heat within. In addition the strut mount also bears the weight of the suspension components when the vehicle wheels drop to a road depression or when the wheel is lifted off the ground. Therefore the strut mount has to be strong enough to support the sprung mass of suspension as well as soft enough to dissipate the vibration. The particular design of the spring in this study had a high rate of premature failure when in use after 25000km-30000km.

The figures 9(a) and 9(b) shows a half sectional view of the rubber spring when subjected to the maximum estimated compressive load.



(a) (b)

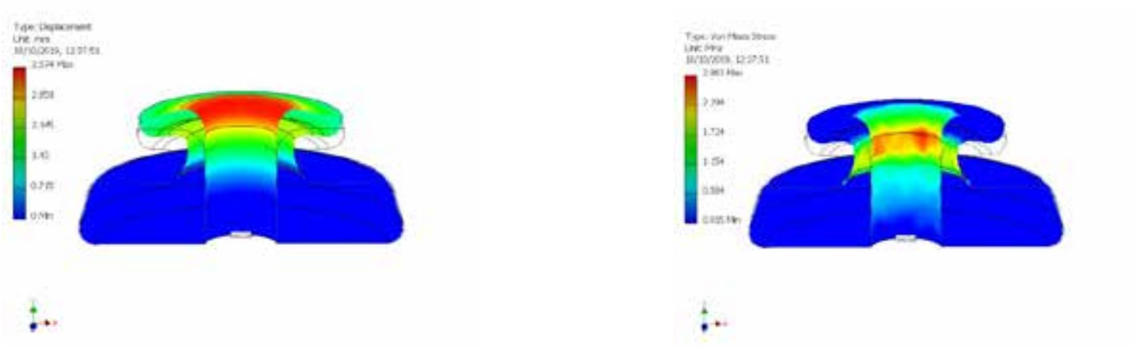
Figure 9: (a) Displacement on compression (b) Stress distribution on compression



(a) (b)

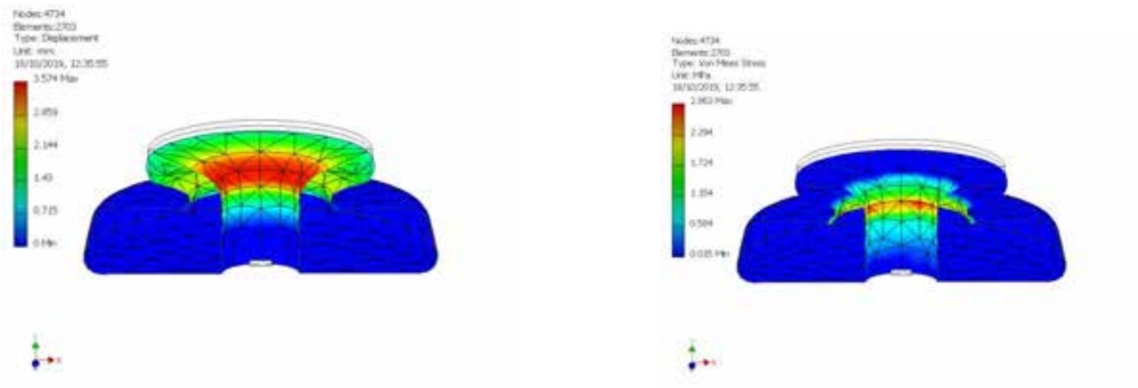
Figure 10: (a) Displacement on tension (b) Stress distribution on tension

Similarly, the figures 10(a) and 10(b) shows a half sectional view of the rubber spring when subjected to a similar tensile load. It has been clearly apparent that the neck region of the spring has a high localized stress concentration which eventually leads to excessive permanent deformation and subsequent play. One approach correct this situation is to alter the cross sectional area of the critical region slightly and excessive deformation in the top region can be reduced by hardening the compound in the given region.



(a) (b)

Figure 11: (a) Displacement on tension (b) Stress distribution on tension



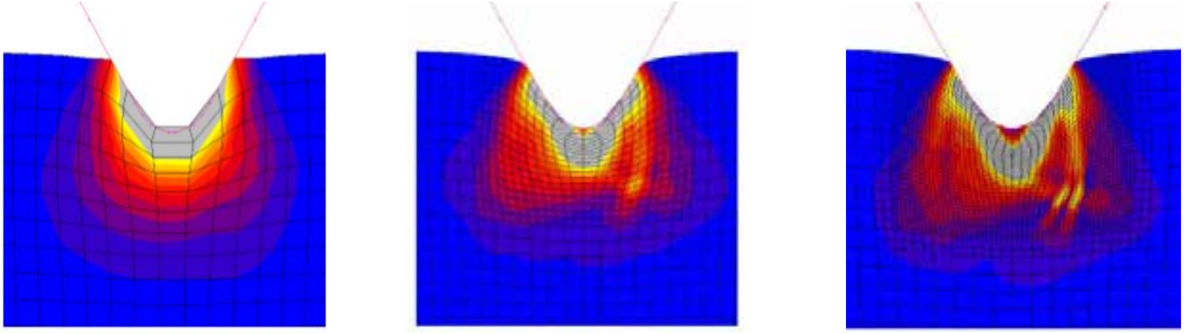
(a) (b)

Figure 12: (a) Displacement on Compression(b) Stress distribution on Compression

Figures 11 and 12 shows that subsequent to the given modification of increasing the minimum thickness in the neck region by 30% and increasing the hardness of the compound by 5 IRHD units in the top region, the maximum stress and the displacement have reduced by almost 50%. On road testing, the component was still in service after 45600km. This product improvement was obtained with the efficient use of FEA with less number of prototypes and hence low design cost and cycle time.

Though the case study is for the polymer based product, FEA is not limited for certain material category. This numerical solution strategy can be applied for any engineering material ranging from soft/bio material to super alloy aerospace material and the geometry lies in the span from nano to macro level.

It is evident in this scenario that higher the number of elements of a domain, number of calculations (stiffness and other mechanical, thermal variables of the domain) raises proportionately. This increases the computational cost in terms of computational resources and solution time. In FEA, contrarily; the accuracy of the solution increases correspondingly along with the number of elements. The illustration shown below elucidates the dependence of the solution accuracy with the number of elements.



(a) (b) (c)

Figure 13: Plastic Strain Contours as depicted by FEA, under the deformation of an spherical nano indenter on a Metallic Glass with different mesh sizes (a) L=10μm (b) L=4.54μm (c) L=2.84μm [4]

Figure 13 illustrates propagation shear bands within the material volume of a bulk metallic glass sample under spherical nano-indentation. It is evident from the above representation that shear bands are clearly visible with the reduction of element size (hence elevated number of elements). Mechanical, thermal or any physical variable to be studied with the FEA should be carried out, along with “FE Mesh Convergence Study”. Mesh convergence study let the FEA personal to aware the minimum size of the element to be divided in par with balanced solution accuracy and computational time.

However, with the development of information and communication technology, in par with the numerical techniques, “Super Computers” are available to study complex problems. Super computer [5] is a computer that has high level of performance compared to a general purpose computer. Currently they are widely used in Molecular Dynamic Studies and Weather Modeling and Computational Fluid Dynamics studies in multi disciplinary areas. As of 2018, the fastest super computer is with Oak Ridge National Laboratory of the United States that can perform 122.3 peta floating point operations per second.

Sri Lanka is still yet to embark to this level and we believe that Sri Lankan government should have proper plan to deploy this technology within the existing industry. The plan should include number of training opportunities on FEA for local engineers to enhance their vision on this. These trainings can be done in local universities or with joint collaboration of foreign institutions. In Sri Lanka, certain number of experts in the field do employ in state universities. But the lack of interest and less exposure about these technologies within the local industries has led the local experts either to conceal with the theoretical knowledge or to develop foreign industries. However there are some positive signs on the development in this aspect with the establishment of Finite Element Analysis and Simulation Center (FEAS Center) at the Sri Lanka Rubber Research Institute premises. Local industries can get the benefit of numerical simulation much easier with the facility.

In conclusion, it is crucial for the government, to formulate some strategies to deploy these international trends in the local industries and move the country towards prosperity.

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