Multi-disciplinary Optimization using LS-DYNA®

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Abstract

Crashworthiness, NVH (Noise Vibration & Harshness) are two distinct as well as very inter-connected attributes/disciplines of vehicle development process. As objectives of both are very differing, it is a challenge to design a vehicle equally performing in both with the global objectives of mass reduction and comfort. LS-OPT® is the tool, which can perform a multi-disciplinary optimization. Here we will perform a frontal crash of the vehicle (/frame) and Optimize as per the FMVSS 208. On the other side, Vibration Analysis and optimization of BIW for the same vehicle will be conducted. Then, we will perform an overarching Multi-Disciplinary Optimization and compare it with the individual optimization. Lastly, we will run a LS-DYNA model with optimized parameters for the validation of the model.

Introduction

Weight reduction is a common objective for every automotive manufacturer and supplier to make the product lighter. As conventional materials are widely used in automotive industries, there are limited options to switch materials within economical range. Other widely adopted weight reduction strategy is to optimize the thicknesses of parts to reduce the weight and saves material cost. Obviously, there are limitations of economical manufacturing processes to reduce the thickness after certain extent but this method proves its effectiveness and as a result automaker as well as supplier bolster about their lighter products. Since, every vehicle sub-system development process must need to satisfy specific objectives, which makes optimization problem complex and it is very crucial to satisfy each objective in desired range with reduced weight.

For every multi-disciplinary optimization, it is very preliminary and important to understand the relation between each attribute/discipline prior to conduct an analysis. Without establishing concrete relationship between disciplines, we cannot interpret the desired results as well as set a realistic goal for optimization. Also, it is very important to conduct an individual optimization of each discipline prior to solve a multi-discipline optimization problem. Which further gives us a broader picture of system response for defined objective and constraints. A selection of objective and constraints also plays a vital role in results of analysis.

In this paper, we will conduct an individual optimization of crash and NVH and compare the results with the baseline model to establish a simple relationship between the parameters and the objective. We will follow this with a multi-disciplinary optimization of both discipline with global objective of mass optimization and low injury criteria according to FMVSS 208.

We will be running simulations on LS-DYNA 9.1.0 version while running single precision for impact explicit analysis and double precision for Eigen value implicit analysis. For this study, we will only run a metamodel optimization and validate the results of it. Direct optimization is computation time costly but there is no doubt about it accuracy.

Simplification of Problem

Here instead of solving a whole vehicle model with 700,000+ elements, we will reduce it to save considerable time and computation resources. Which will give us capabilities to conduct iterative study easily without loss of actual goal to reduce weight and improve the safety and vibrations.

In frontal crash, structural frame plays a major role in energy management. We can see reduced frame model in fig.1 without body, engine, transmission, suspension system, exhaust system, interior.

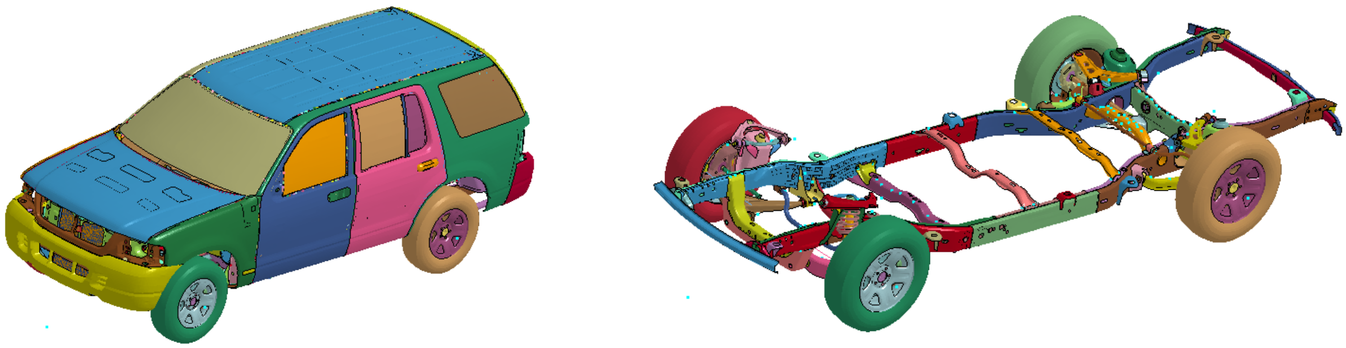

Fig. 1) Reduction of Vehicle model to Frame

Here to restore the mass and inertia of frame model to represent the exact same physical characteristics, we must have to add mass and inertia of the removed parts to the center of mass and connect that center of mass to the body and engine mounts.

In vibration analysis, instead of analyzing the whole vehicle model, we will reduce the model to BIW (Body In White). The only reason behind this is to reduce the complexity of the problem and remove the small and fragile part out of the consideration. Since, it will take the most of eigen value and eigen vectors during an analysis. Also, it will help us to focus on BIW only and improve its natural frequencies of vibration. The important thing to note here is removing the excess spot-welds after the reducing of parts, which can constrain the body and may lead to incorrect results.

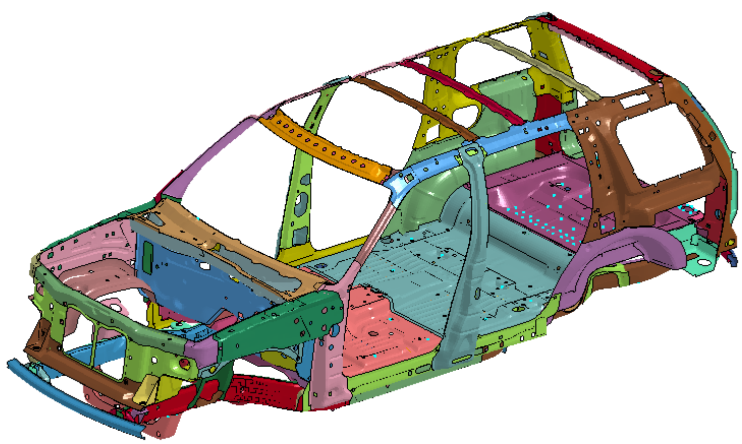

Fig. 2) Body in White of Vehicle

Frontal Crash Optimization of Frame

For optimization, we must have to identify the parameters and give a logically wide range to provide algorithm a good degree of freedom. In this case, we will choose the thickness of rail and bumper as a parameter and will give range on both sides of the original thickness as a continuous variable. Here mass reduction is a main objective of optimization analysis.

Objective	Constraints (Range)
Minimize mass	HIC (650-700)

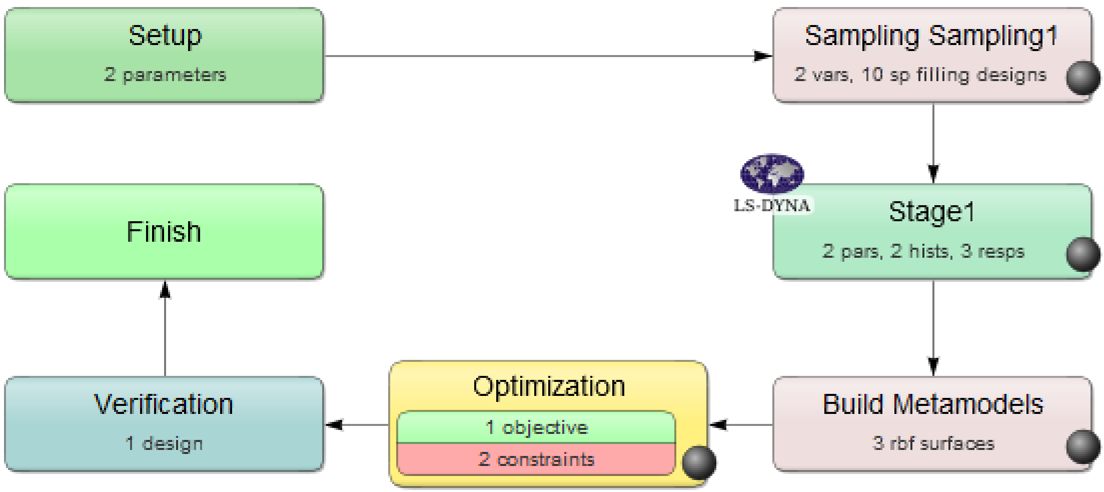

Fig. 4) LS-OPTui for Crash Optimization

Here we can see that, we did not assign HIC as an objective of an analysis but as a constraint. The most logical reason behind it is we know the maximum possible injury criteria for passing of any frontal impact according to FMVSS 208. So, the only unknown for the given criteria is Mass. Defining such a simple algorithm can give you most optimized mass for the required injury criteria. Since Safety ratings are major marketing strategy, companies usually set very stringent criteria then FMVSS and IIHS for their Safety engineering teams.

Results of Crash Optimization

For optimization, we are using metamodel of Radial Basis Function Network with Space Filling point selection and default number of simulation points.

Thickness parameter	Baseline	Optimized
Rail	4.00	3.58
Impact Bar	2.50	2.90

Results of Objective and Constraints:

	Baseline	Optimized
Mass	54.14 kg	49.49 kg
HIC	774.26	663.25

We achieved a considerable 8.6 % reduction in mass as well as injury number with an optimization of thicknesses.

NVH Optimization of BIW

For an optimization of BIW of medium size SUV vehicle, ABC&D pillars and roof cross member plays a major role in resisting the vibration. Also, it is very important to have a low floor vibration. We will choose following parameters based on this understanding.

Here we will select the thicknesses of A&D pillar, roof cross members as well as rear side floor as parameters solely based on the baseline observation of eigen modes. Also, it is important to note that, we do not have any specific target such as HIC in crash optimization in this analysis and we want to reduce the mass and frequencies of modes. So, it is logical to take Mass as well as Frequencies as an objective.

For optimization, we are using polynomial metamodel, linear with iteration with D-Optimal point selection for default number of simulation points, where all parameters are continuously variable within a given range.

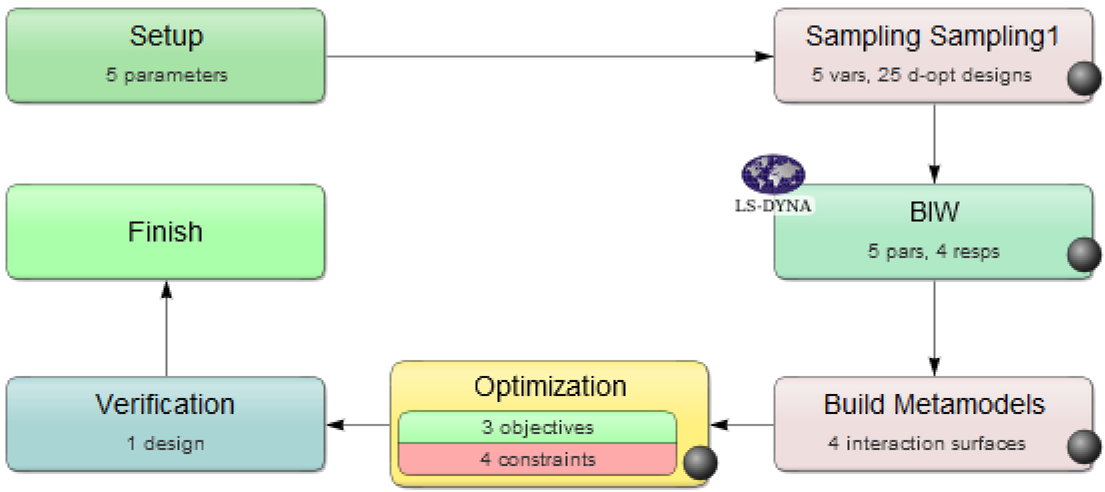

Fig. 5) LS-OPTui for BIW Optimization

Results of BIW vibration optimization

Thickness parameter	Baseline	Optimized
A pillar	1.20	0.70
D pillar	0.95	0.70
Roof cross member	2.24	2.50
Rood Side member	1.00	0.80
Floor	0.82	0.50

Mode Type	Mode Number	Baseline (Hz)	Optimized (Hz)
Floor	1	13.22	12.37
Torsional	2	15.86	15.02
Bending	5	19.78	19.52

Here we obtained a mass reduction of 6.71 kg in BIW of vehicle, which is almost a 1.11% of the baseline mass with an improvement in natural frequency. Floor mode is completed recovered as well as intensity of torsional and bending mode is decreased. Here we can also observe from thickness increment of roof cross member that, its strength is very important for retaliating torsional and bending, while other thicknesses are reduced.

Multi-disciplinary Optimization

From above study we can conclude that, optimization is an obligatory step but without multi-discipline optimization, we cannot conclude that the vehicle will have the satisfactory performance based on two distinct optimizations. As per the result of BIW optimization, reduction in thickness is good for above NVH analysis but, we know that its strength plays a major role in securing collapse of occupant cage and consequently improve the occupant safety during frontal impact and roof strength. If we add rails into an analysis, more thickness of rail improves the bending mode frequency but at the same time it will increase the mass of vehicle.

In the following section, we will perform a multi-disciplinary optimization of Crash and NVH. Finally, we will compare and discuss the results of analyses. We are using the same parameters as crash and NVH analysis for multi-disciplinary optimization.

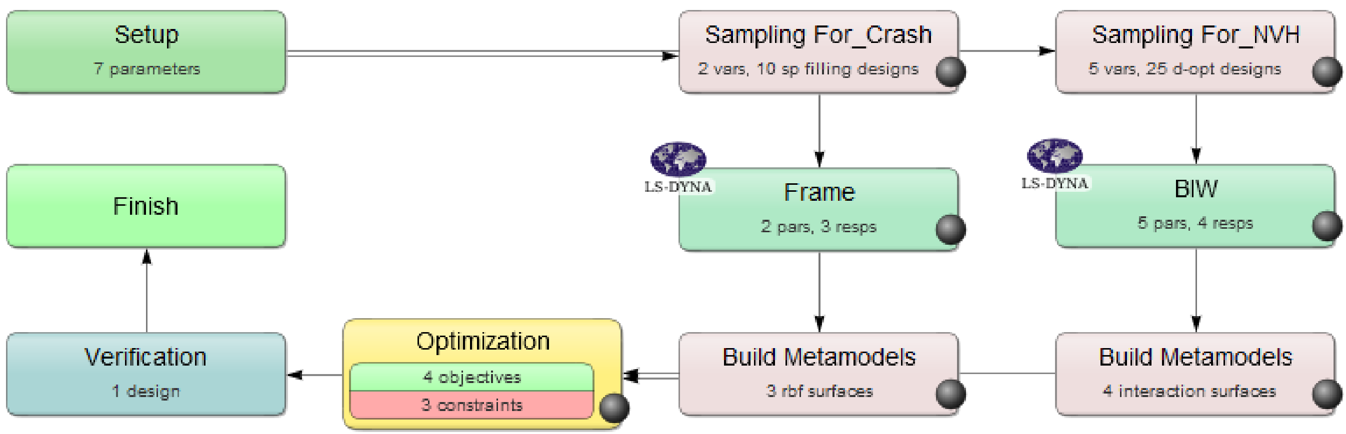

Fig. 6) LS-OPTui for Multi-disciplinary optimization

Objectives (Minimize)	Constrains (Range)
Mass of Frame	Mass of BIW (-%5 to +5%)
Frequencies of three modes	HIC (650 to 700)

Here we are using two different techniques for sampling of each discipline, which are same as an individual optimization. We can also set same sampling technique for both. Objectives and constraints for the multi-disciplinary optimization are as per shown in above table. We can set desired logical range as per our requirement.

Results of Multi-Disciplinary Optimization

Following are the change in thicknesses of chosen parameters.

Thickness Parameter	Baseline, mm	Optimized, mm
A pillar	1.20	1.70
D pillar	0.95	0.92
Roof cross member	2.24	1.24
Rood Side member	1.00	1.08
Floor	0.82	0.92
Rail	3.80	3.50

Here we can observe from the results that, thicknesses of A pillar and roof side rail is increasing which are good for improving occupant cage structural integrity and upper body structure. An increase in floor thickness will improve the frequency of floor mode.

Results of mass and frequencies of modes are as follows

Objective/Constraints	Baseline	Optimized
Mass (Frame), kg	51.05	29.70
Mass (BIW), kg	603.08	602.57
HIC	774.26	675.63
Floor Frequency, Hz	13.23	12.49
Torsional Frequency, Hz	15.86	14.52
Bending Frequency, Hz	19.79	19.61

We can see from the table that, we obtained a significant reduction in mass of frame as well as mass of BIW. Frequencies of modes also reduced by a small extent in multi-disciplinary optimization. We will check the optimized results for its authenticity by following with validation analysis.

Validation of Optimized results

We will run a LS-DYNA simulation for frontal crash as well as NVH analysis with an optimized value and compare with the optimization results for validation.

Comparison of optimization and validation analysis are as follows

Objective/Constraints	Optimized	Validated
Mass (Frame), kg	29.70	29.70
Mass (BIW), kg	602.57	602.57
HIC	675.63	678.26
Floor Frequency, Hz	12.49	12.65
Torsional Frequency, Hz	14.52	14.53
Bending Frequency, Hz	19.61	19.15

We can clearly see from the results that, results of optimization are converging. Here we gained a good confidence of an analysis for mass reduction with better safety and NVH properties.

Conclusion

We can conclude from this study that; multi-disciplinary optimization is an essential procedure which gives a broader insight of a multi-disciplinary problem with computer aided tools for improvement in vehicle performance. LS-OPT is a versatile optimization tool with a variety of metamodel optimization algorithms and direct optimization. Which makes it very competitive optimization tool. We can see from the validation results that metamodel optimization are accurate enough. We can also follow metamodel optimization with a direct optimization for higher accuracy and authentic results.

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