Small-overlap Crash Simulation Challenges and Solutions

Sri Rama Murty Arepalli, Ganesh Kini, Roshan MN, Venugopal Thummala and Andrea Gittens

ESI Group

1 Introduction

Insurance Institute of Highway Safety, USA, introduced the small overlap crash test in 2012. As usual this new regulation saw many cars failing to pass the proposed rating. The damage pattern is seen mostly concentrated away from the longitudinal structures which normally absorb and dissipate the energy, with no definite crush zone and less protection along outer edge of the car body. The vehicles which normally are rated highly for regulation tests failed miserably in the small offset overlap tests. The law of physics prevailed, as there was not enough protection and these crashes resulted in serious and fatal injuries. Different car companies have come up with several solutions. As it is a new regulation, the simulations face issue of time for identifying the cause and effect of intrusions and rating them as per IIHS. As the regulation calls for more and more simulations, there exists a need for pre- and post-processing tools to quickly identify the IIHS ratings.

2 Scope of the Study

LS-DYNA solver is used for the studies. ESI Group has developed tools to handle this challenge. The studies are made on a public domain vehicle model. A template in Visual-Process Executive sets up a frontal crash model and places different overlap barriers with appropriate offsets. A macro in Visual-Crash DYNA allows iterating with the materials for the components in the critical load path. Finally, a template in Visual-Viewer plots all the intrusions and shows the IIHS ratings.

3 Tools Used for Study

Following tools are used for the study for effective conduct and control of simulation.

3.1 LS-DYNA

LS-DYNA is a general-purpose finite element program capable of simulating complex real world problems. It is used by the automotive, aerospace, construction, military, manufacturing, and bioengineering industries. LS-DYNA is optimized for shared and distributed memory environment on UNIX, Linux, and Windows-based platforms. The code's origins lie in highly nonlinear, transient dynamic finite element analysis using explicit time integration.

LS-DYNA solver is used for the number crunching for the entire study. `*MAT_RIGID` card is used for making barriers as non-deformable and to fix the barriers in position. `*PARAMETER` card is used for defining and iterating the material references of the load carrying members.

3.2 Visual-Environment (VE)

Visual-Environment is a flexible and open engineering platform, addressing multiple simulation domains. Visual-Crash DYNA (a module of Visual-Environment), a comprehensive preprocessing tool, is used in the study, for setting up the compute models to solve in LS-DYNA. Visual-Process Executive (another module of Visual-Environment) is used for automating the model preparation steps, which internally uses macros to speed up and automate the tasks. Visual-Viewer templates are used for post-processing and reporting.

4 Preparation

This section describes the preparations and modelling.

4.1 Vehicle Model

For the study a public domain model from the NCAC model library is considered. This model is pre-validated before using for simulation set ups. Pre-processing checks are done to ensure that no modeling errors exist. An advanced material library is setup for the model containing several High Strength material definitions. The parts (components) that are important for small overlap crash are pre-identified based on the experience and studies carried over elsewhere. To all these parts, the material references are made using ***PARAMETER** card. These parameters are later updated by another macro based on the material model considered for any particular simulation. A model-coordinates file is created, to identify various intrusion points. A Visual-Process Executive template picks up this coordinates file, finds the nearest nodes to the points given in the file and defines the time history output request.

4.2 Barrier Model

For the study 3 kinds of impacts are considered. Two cases represent Barrier Impact, one case represents vehicle against another vehicle. The two rigid barriers are created as per the dimensions provided by IIHS, one with 150 mm radius and another with 50 mm radius. For both these barriers, the front face of barrier is modeled using 5 mm shell mesh.

A Visual-Process Executive template models the geometry of barriers with different radii. In this study the radii used are 150 mm and 50 mm. The barrier material is regular steel material and all the parts are modeled with ***MAT_RIGID**. The constraints options available in rigid material card are used to support the structure. The third impact case, i.e. impact against another vehicle (similar public domain model) impacting from opposite direction with a speed of 64 km/h.

4.3 Data Organization

This study uses a specific convention for naming the files. Each run is treated as an iteration of the simulation. The format adopted here is as below:

Run<n>_<velocity>_<barrier_type_radius>_<material_scheme>.key

For example : "**Run1_64kmph_rigid150mm_MatScheme1.key**",
          "**Run10_64kmph_vehicle_MatScheme2.key**"

This naming convention is used to identify the runs for further filtering of iterations during post processing and reporting. This naming convention helps to filter out the runs based on some parameter. For example, Engineer can filter out all the runs with rigid barrier 150 mm. The Tool requires the Engineer to input the base directory containing the results of the iterations. Form the base directory the tools searches recursively and organizes the information of all the runs based on the input file names.

5 Approach

During the course of model setup operations, the following steps are followed:

1. Vehicle model is pre-validated and made ready for the use in simulation.

2. A Visual-Process template loads the vehicle model and the barrier model. If the barrier model is of rigid barrier type, based on the input creates the curved portion of the barrier with different radius. The process will also position the barrier automatically with correct offset and overlap. Visual-Process defines the velocity with ***INITIAL_VELOCITY** card with iteration specific speed values.

3. For this study velocity used is 64 km/h. Visual-Process also reads the contact templates from the User Local database and updates the appropriate slave and master entities using ***SET_PART cards.**

4. Three contacts are created, one ***CONTACT_AUTOMATIC_SINGLE_SURFACE** card with all the vehicle parts. Another ***CONTACT_INTERIOR** card for all the foam components of the seat, and thirdly a ***CONTACT_AUTOMATIC_NODES_TO_SURFACE** between barrier and vehicle.

5. Visual-Process creates the iteration model with vehicle and the barrier as unique files i.e. using ***INCLUDE** cards. It updates all the ***PARAMETER** cards appropriately for material definitions.

6. Generated models are submitted to LS-DYNA solver through the scripts associated to Visual-Process. Though Visual-Process can integrate various job submission tools, for this study, a script is run on the same workstation where the model was created.

7. A Visual-Viewer macro runs through the MATSUM results file and automatically identifies the top components which take on maximum energies. This macro determines all the parts that are required to be enhanced in strength either by structural re-design or by enhancing material properties. The current scope of the study is limited to changing the material properties only.

8. A Visual-Viewer template runs through the results, post-processes and creates an IIHS ratings chart and other important plots.

9. All above steps describe model setup procedures.

6 Automated Model generation using Visual-Process Executive for Small Overlap Test

The manual method of setting up the models for various impact cases are generally quiet time consuming and often can have some element of person to person variation in terms of accuracy and consistency. The use of automation tools becomes the need of the hour to setup the models with intended iteration setup as quickly and as consistently as possible.

ESI's Visual-Process is a time tested industry standard application that is most suited for such automated model building activities. The tool also comes bundled with automated report generation capabilities as well.

For the current case in consideration a Visual-Process template was setup considering all the technical details involved in the model setup for small overlap impact cases. This tool serves as a guided approach to the designer, simplifying the arduous task of multiple model generations. The designer is required to create some standard LS-DYNA entity definition files for contact creation, output controls, material models, etc.

The models thus generated are LS-DYNA solver ready. Upon successful solver termination, each iteration result will be available in the local results directory, making it easier to identify and sort.
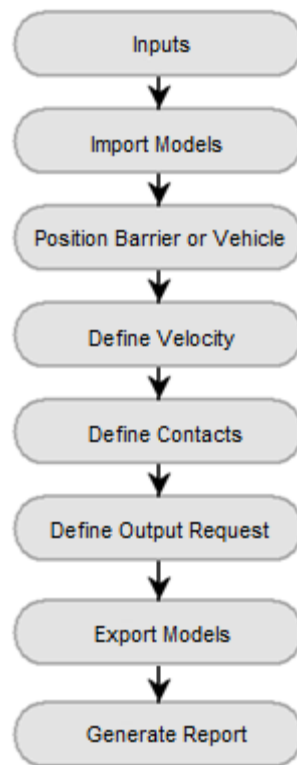
Fig.1: Process Flow Chart of Visual-Process template for Small Overlap Test

7 Automated Macro for updating Material models

Considering the baseline models are successfully generated for the 3 impact cases (viz, Impact with 150 mm radius rigid barrier, Impact with 50 mm radius rigid barrier and Impact b/w Vehicle to Vehicle), the designer is faced with the challenge of the first short listing the parts to update the materials and subsequently changing the material models.

Visual-Environment offers a plug-in environment to quickly develop macros using python scripting language.

The macro developed for updating, first scans the results of the baseline iteration, to shortlist the parts absorbing the maximum impact energies. They are graded as per their energy absorption limits, and the top ten among them are notified to the engineer. The engineer then is allowed to iterate by assigning various high strength materials to these parts picked from the advanced material library. The models are then submitted to the LS-DYNA solver again for new simulation results.

8 Automated Report Generation

A special interface was created in Visual-Process for the engineer to quickly filter iterations and select the runs for report generation. The interface provides a filter and a convenient table to show the filtered runs. The filter option is designed to assist the engineer to search for iterations based on particular parameter. For example, engineer can filter out all the runs where impact is against rigid barrier with 150 mm radius. The filter also supports cascading sequence of filters. For example, engineer can search in following sequence. Filter all rigid barriers → Get all 150 mm Radius barrier iterations → with Material scheme 2. This way engineer can easily get all the runs that are required to be compared or reported. The interface contains also a tabular view of the filtered results. This table provides a quick over view of all the runs filtered. Once the key iterations are shortlisted, Visual-Process with the assistance of Visual-Viewer's features generates customized reports either as a standalone report or a comparison report. This is done considering the engineer's preference of the

parameters chosen for the report. The various sections of the report are detailed in the Appendix section.
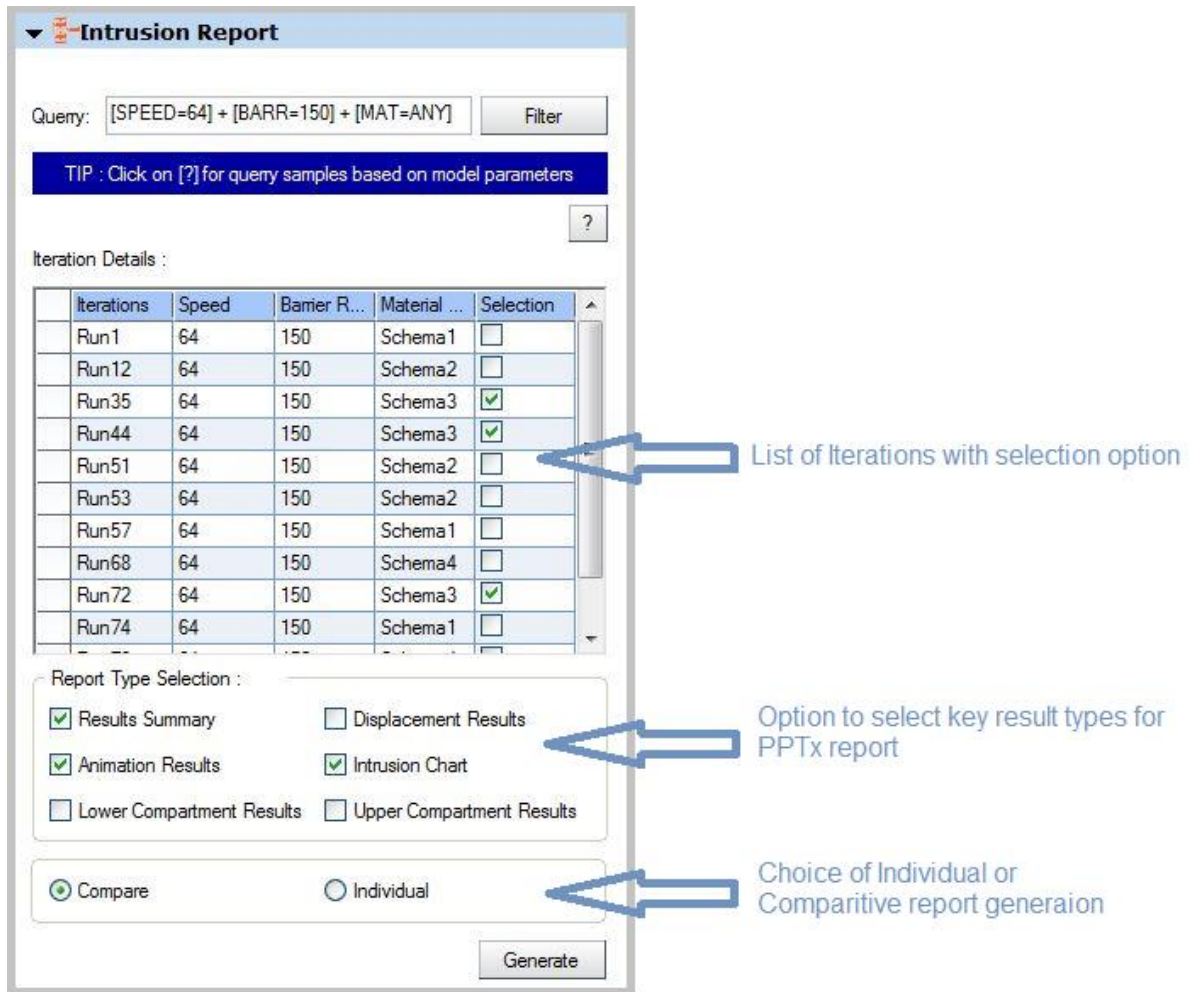

Fig.2: GUI for report generation options

9 Key Iterations and observations

This paper considers some key iterations and the observations of the kinematics thereof.
The first set of iterations can be termed as baseline iterations for the below cases.

1. Impact with 150 mm radius rigid barrier
2. Impact with 50 mm radius rigid barrier
3. Impact between two Vehicles

The final set of iterations can be considered as the materially strengthened iterations for the same impact conditions.

1. Impact with 150 mm radius rigid barrier with different materials
2. Impact with 50 mm radius rigid barrier with different materials
3. Impact b/w Vehicle to Vehicle with different materials

9.1 Case Comparison 1:

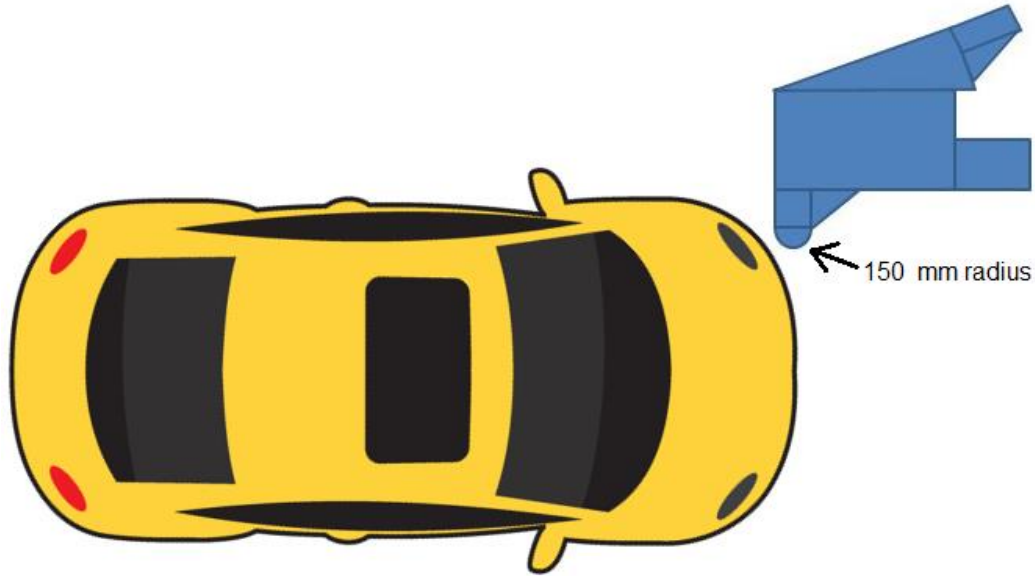Impact with 150 mm radius rigid barrier with normal & with high-strength steel material
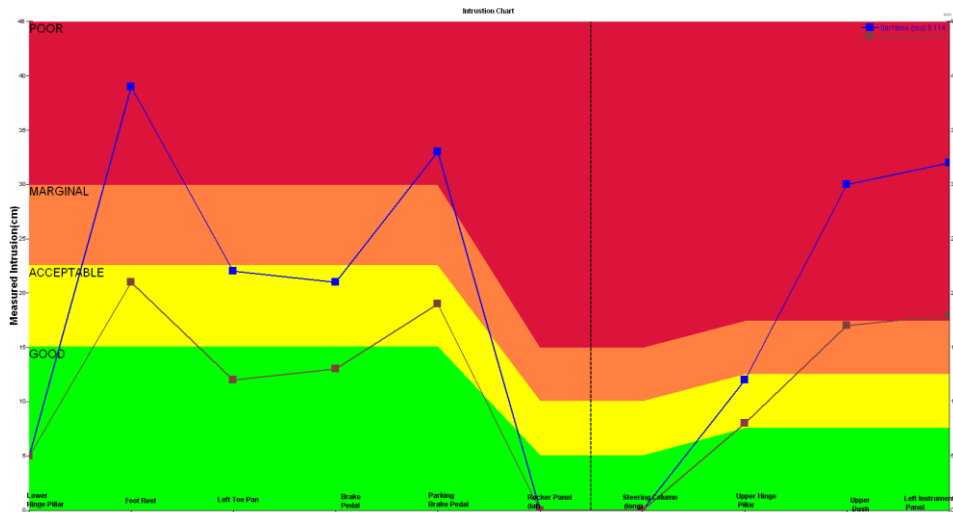
Fig.3: *Impact against 150 mm radius barrier*

Fig.4: *IIHS intrusion chart, comparing the iterations without and with high-strength material*

Key Observations indicate: When the high-strength material was assigned to the key components in the load path, the behavior has been significantly better than baseline. The door has also not opened.

From the top view comparisons of both iterations, it is noticeable that the windscreen is severely damaged in the baseline iteration, but the windscreen is less deformed in the high-strength material iteration. Also because of the high stiffness the yaw is seen to be significantly higher in models when the stronger materials are used.

The IIHS intrusion chart also shows significant reductions in the intrusion values when high-strength steel material was used. Few intrusion levels reach good and acceptable zone from poor corridor.

9.2   Case Comparison 2:

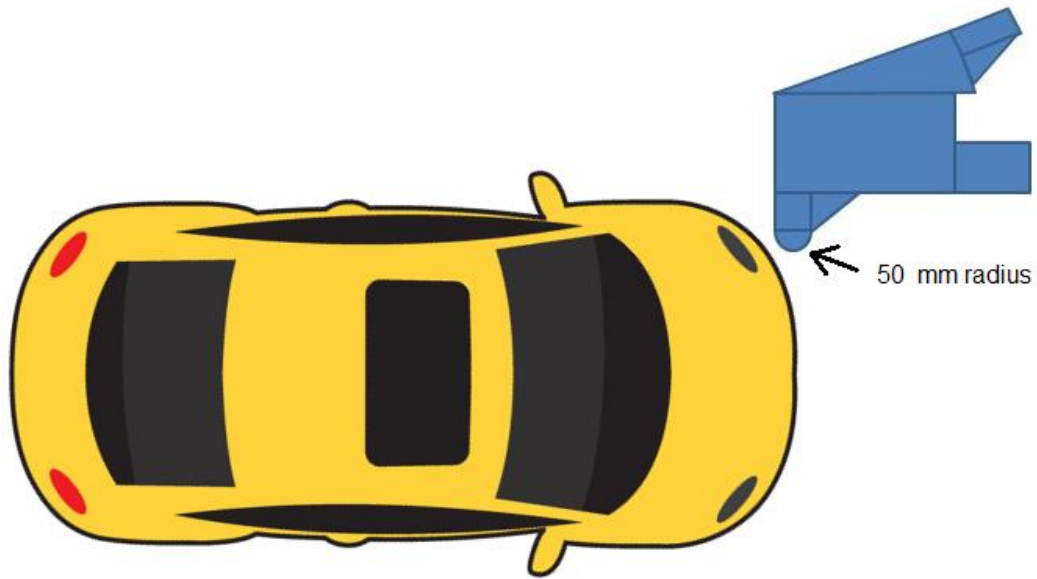Impact with 50 mm radius rigid barrier with normal & with high-strength steel material

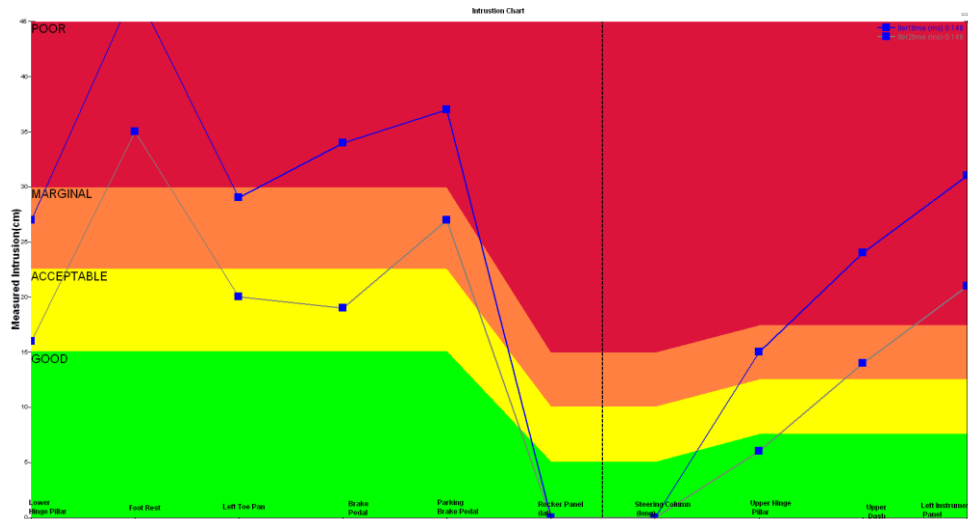*Fig.5: Impact against 50 mm radius barrier*

Fig.6: IIHS intrusion chart , comparing the iterations without and with high-strength material

Key Observations indicate: Similar to 150 mm rigid barrier impact case, even in this case, when the high-strength material was assigned to the key components in the load path, the behavior has been better than baseline. The door has also not opened and the windscreen damage is also lower.

As the barrier radius (50mm) is comparatively very lower than previous barrier (150mm) the yaw is seen to be significantly higher even when the materials are strengthened.

The IIHS intrusion chart also shows significant reductions in the intrusion values when high-strength steel material was used.

Floor and toe pan intrusions are also significantly reduced.

9.3   Case Comparison 3:

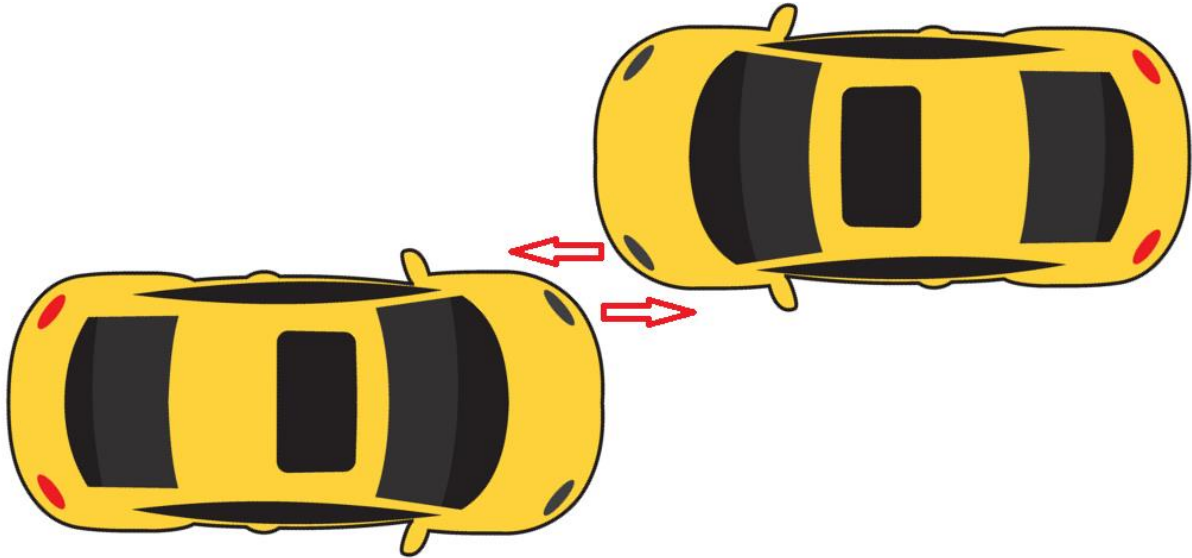Impact b/w Vehicle to Vehicle without & with high-strength steel material

Fig.7: Vehicle to Vehicle Impact

Key Observations indicate: In this case, the Vehicle collides with another similar vehicle. It is noticed that since, both structures are equally deformable; their impact energy gets absorbed by both vehicles through the components coming in the load path. Here extended length of the vehicle with higher mass/inertia also prevents that yaw of both vehicles.

The front rail experiences more shear forces and gets deformed along transverse direction of the vehicles. There is also notably significant intrusion into the vehicle near the driver side. The doors hinges also give away and the door opening is noticeable.

Among the three cases, this impact condition appears to be the most severe, as there is high intrusion into the passenger compartment. The reduction in survival space indicating the severe leg injury possibilities also directs the designer to look into further strengthening of the doors.

The IIHS intrusion chart does not show significant reductions in the intrusion values when high-strength steel material was used.

10 Conclusion

From the above studies it can be well established that the IIHS small overlap case exposes a serious concern to occupant safety and much has to change in the vehicle design aspect to accommodate occupant safety needs.

The study also lays out a path for the future research viz ;
   - o Going beyond the material changes, to the structural & geometric design of the components in line of vehicle impact load path.
   - o The need for a world class automation tool while designing the experiments also becomes inevitable to quickly setup the models and generate reports.
   - o Management of iterations will become very simplified with the adoption of a state of the art platform like ESI's Visual-Environment comprising modules, offering model generation, auto identification of sensitive components in the load path, iteration report generation. These features enable the designer to use his time effectively to design the experiments, have a consistent and error free model generation and standardized reports which serve as historical evidence for experiments conducted providing invaluable insights into future design change iterations.

11 Literature

References are given below:

[1]   IIHS, "Frontal Small Overlap Crashworthiness Evaluation", Crash Test Protocol Version 1,
        March 2012,
[2]   NCAC, "2010 Public domain model, Detailed Model (Additionally Validated Version)",
        Crash Test Protocol Version 1, March 2012,

12 Appendix :

PPTx report generated by Visual-Environment for an individual iteration

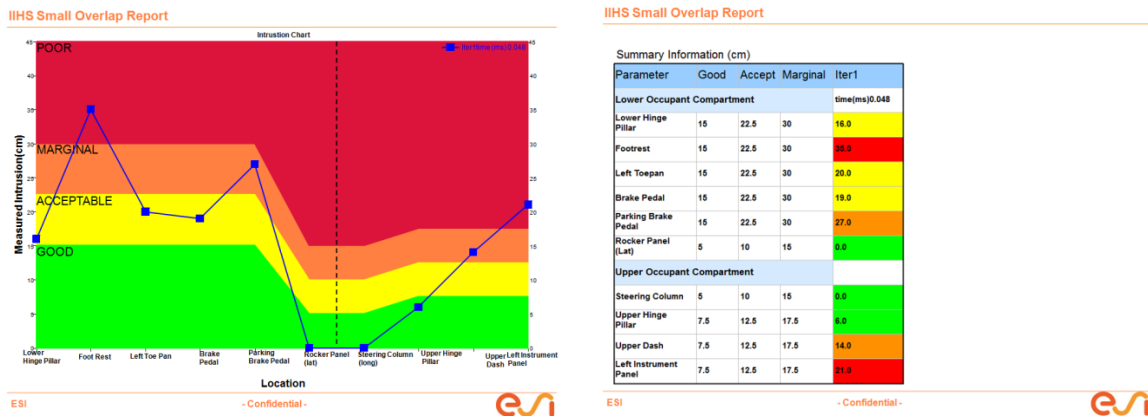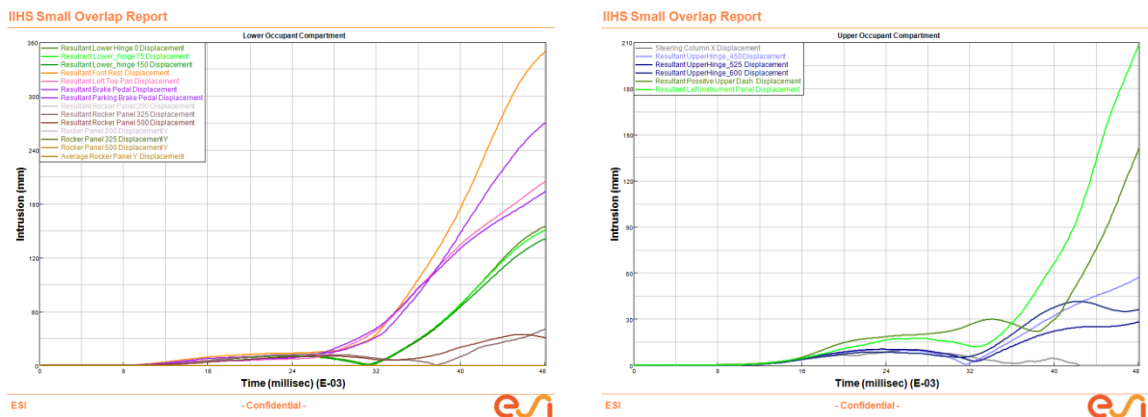*Fig.8:   Intrusion chart & Summary Information*

Fig.9:   Plots of Lower & Upper occupant compartment