Agile Dummy Model Development Illustrated by Refinement Activities of the WorldSID Shoulder Model.

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1 Introduction

The Agile Software Development is a method that promotes adaptive planning, evolutionary development, early delivery, continuous improvement, and encourages rapid and flexible response to changes. This method is established in the development of software and influences also many other development processes. The employees at DYNAmore are developing dummy models together with a consortium of car companies since decades. The models are used world wide by almost all automotive companies that run LS-DYNA to design their restraint systems.

The process of creating the models has been refined several times. The paper describes the applied methods for one of the latest dummy model developments, the WorldSID 50% dummy model. Although the model quality is already high, there is still a frequent exchange between the developers and customers to refine the model for specific load cases. The input and interaction with users is highlighted by the adaptations made for the shoulder area and other detailed investigations.

Finally, the paper compares the applied methods with the methods published for Agile Software Development and concludes with ideas to further optimize the processes to develop dummy models.

2 Dummy Modeling process at DYNAmore

The dummy modeling process which is described in this section is applied in several FAT and PDB projects. The dummy activities are enhanced and adjusted to the needs of the industry since 19 years. The main members of the Groups are several Suppliers of Germany and the big five OEM's of the German automotive industry AUDI AG, BMW AG, Daimler AG, Dr. Ing. h.c. F. Porsche AG and Volkswagen AG.

The members of the groups defined continuously the quality requirements of the models and guided also the development process. They are also involved in the definition of the validation test matrix and the needed load levels for specified tests.

The models which are developed in these working groups are mainly side impact dummy models and one rear impact dummy model:

- EUROSID
- ES-2
- ES-2re
- WorldSID 50%
- USSID
- SIDHIII
- BioRID II (rear impact model)

All these Models are frequently used world-wide and updated continuously to new validation tests and the requirements of the users world wide.

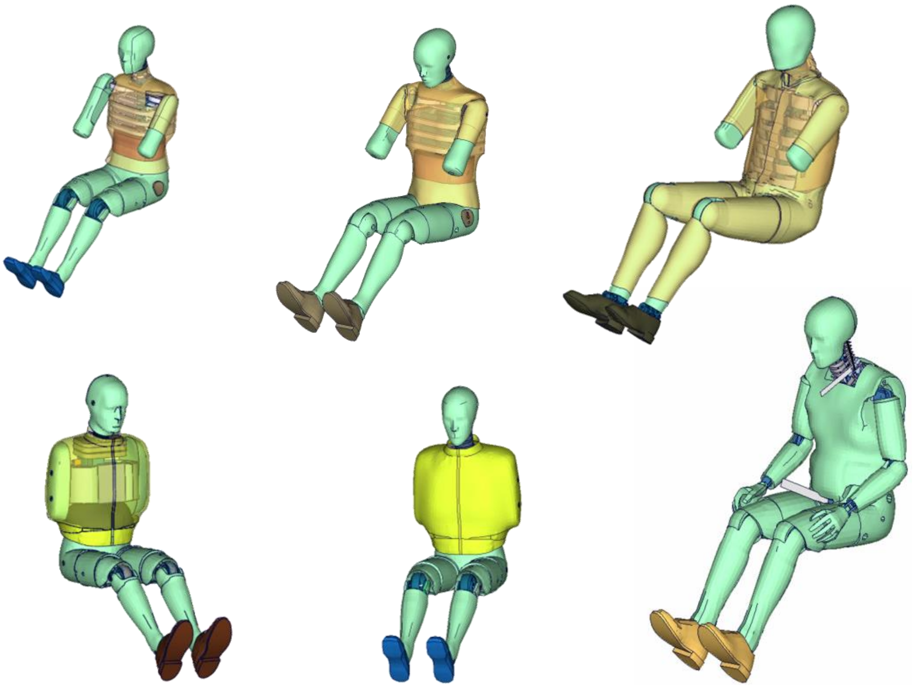

Fig.1: FAT and PDB dummy models of DYNAmore

2.1 Model building and Mass validation

For models which start from scratch, the mesh is generated based on CAD Data which is offered by the working groups. An element size of about 5mm is used. In use of this mesh size, most details which are necessary for the validation can be captured and constructed useful. Target time step size is about 0.9 µs with a maximum of 1% added mass. Additionally laser scans can be used to adapt the model to geometry changes due to assembly, gravity or manufacturing distortions. The first two issues can also be adapted by using assembling pre-simulations to put all parts together. As example the jacket a pre-simulation can be named. The jacket mesh is done based on pattern and put on the dummy by pre simulation. The resulting jacket position and geometry often fits very well to physical dummy.

If the mesh is accurate enough, the mass validation is no more complicated and by using physical density values for the materials the mass validation and determining the exact inertias for each single part is quickly finished.

2.2 Material Tests

The basis for the finite element models are the material tests of all relevant materials. The test specimens are usually cut out from new original parts of a dummy. Some of the specimens were taken from repair kits. Figure 2 shows the pelvis and arm flesh of the WorldSID 50% after cutting by a water jet.

Fig.2: Pieces for material probes of WorldSID 50%.

All relevant deformable materials are tested dynamically and statically. For instance for the WorldSID, the vinyl of the head, pelvis and upper leg skin, the Hyperlast materials of the upper arm and the pelvis, plastics of the arm bone and iliac wings, the foam of the pelvis and thorax rib pad and the Nitinol were tested.

Fig.3: Material specimens of the WorldSID 50%.

The main focus on the material tests is on the dynamic behavior. Thus, all parts are tested by different strain rates like 0.001 1/s, 20 1/s, 100 1/s and 400 1/s in tension and compression. Also static tension and compression tests are performed. For rubber-like materials additional compression tests with constrained lateral expansion are carried out.

The material test results are often used after smoothing as direct input for the LS-DYNA material definitions. Therefore, material models that allow such test curves as input were preferred like *MAT_FU_CHANG_FOAM or *MAT_SIMPLIFIED_RUBBER. For many material definitions the unloading behavior is also included. This behavior is important to correlate signals that occur after a first decay of the main pulse. E.g. neck forces depend significantly on the overall kinematic behavior of the dummy, which depends on the loading as well as on the unloading characteristics of the materials.

2.3 Component tests

In addition to the material tests the major sub-assemblies are tested on the component level. The component tests are used to ensure that each body region correlates accurately in the validation domain. All important components of the FAT and PDB models are tested and validated.

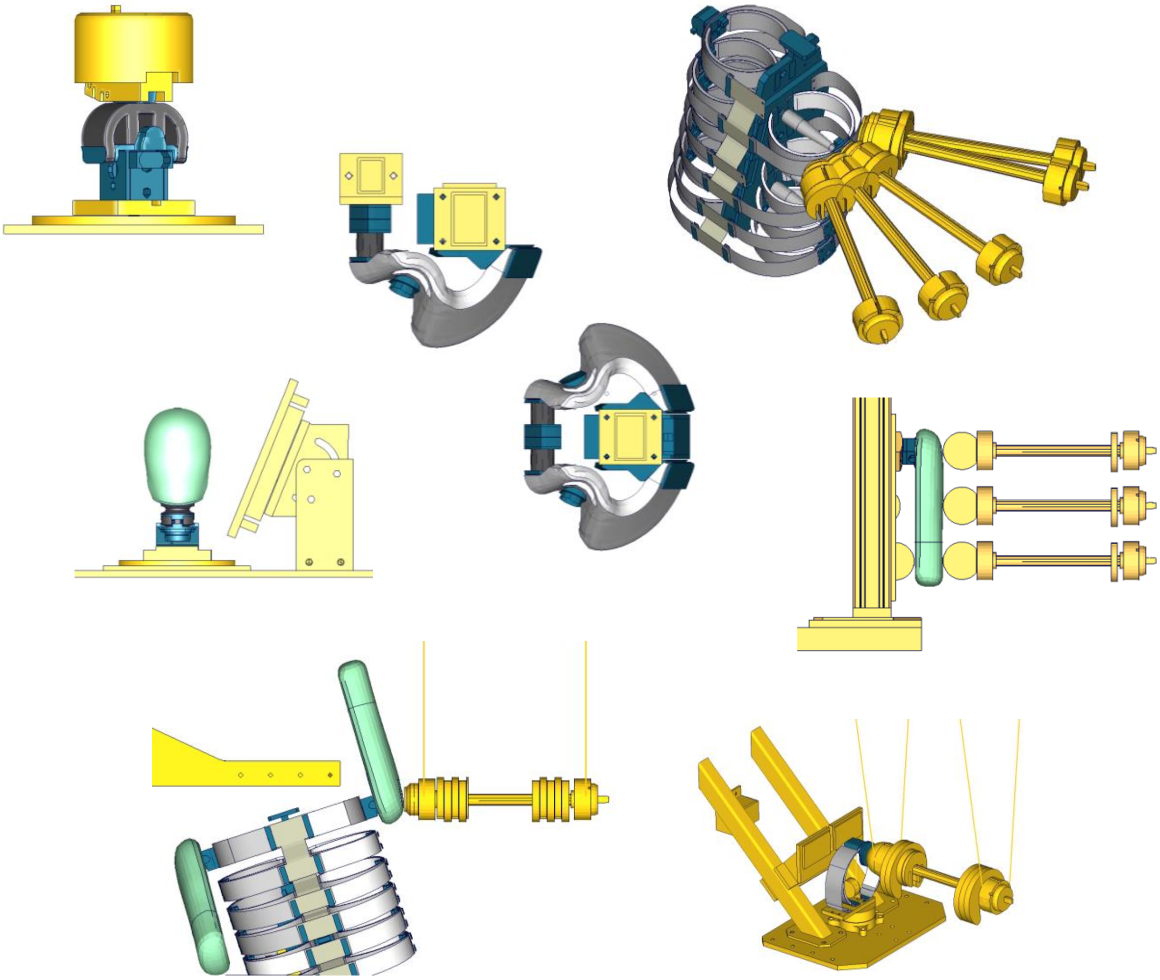

Fig.4: Used component test for validation of WorldSID 50%

The main difficulty of the component tests is to find simple tests with loading conditions which are similar to the loadings in a vehicle. Therefore, a lot of pre-simulations are done to find the right test set-up and the appropriate loading levels.

2.4 Sled tests

The main validation tests beside the calibration tests of a full dummy are sled tests. These tests are configured to load the dummy in a similar way to loads of a vehicle. For each dummy several shapes of the barrier are used.
The sled tests are performed by using different arm positions and also some tests are done without jacket and without arm.

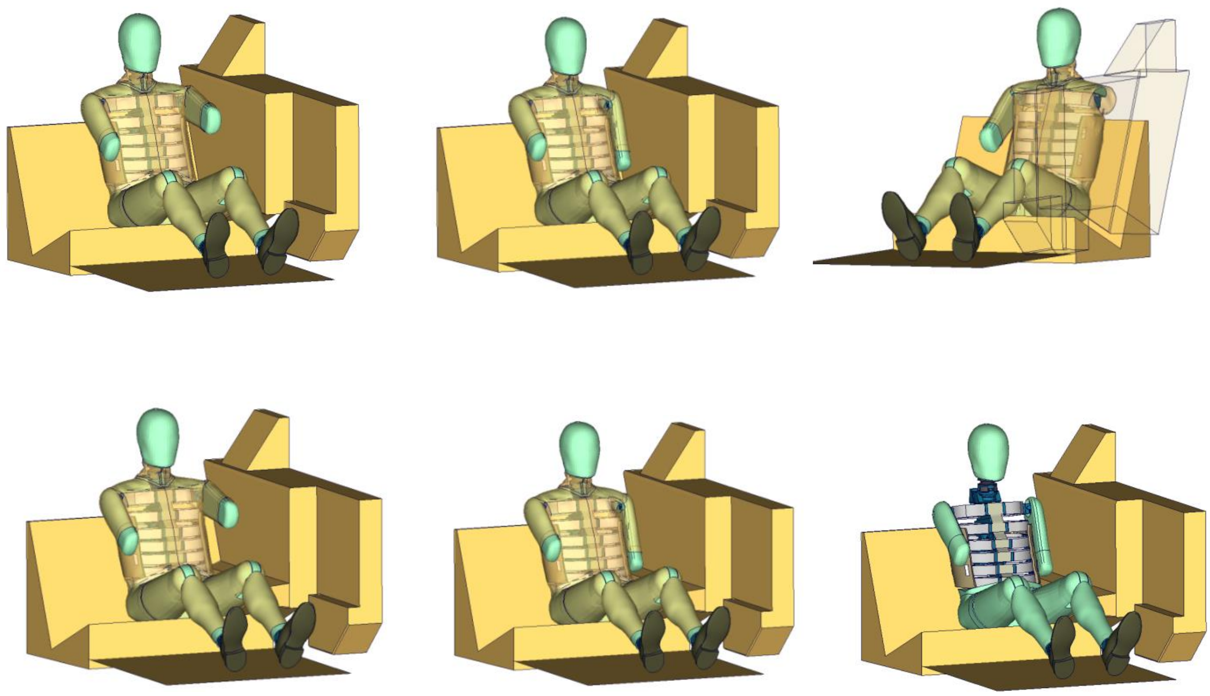

Fig.5: WorldSID 50% validation sled tests.

The different shapes of the sleds are chosen to force kinematics of the dummy that can be observed in a vehicle load case. These tests are the most important validation load cases for the FAT and PDB dummy model development.

3 Validation process at DYNAmore

The validation process is a sequence of loops through the above explained tests. It starts with a detailed mesh and a mass validation. In the next step the material tests are defined and the results are used to generate material cards. This leads to a first model, which can be used in a vehicle simulation to learn about the load levels and load characteristics.

The model is then used to define appropriate boundary and initial conditions for a set of component and sled tests. With the test results the model can be enhanced. The new enhanced model can then be used again in vehicle simulations and the loop starts again. During each loop new test are defined and performed based on the gained knowledge where the model has to be enhanced.

Defining and performing all tests in the beginning of a project is likely to lead to a weaker test database. This becomes even more obvious if we take into account that sometimes the hardware might not be totally finalized when a modeling project starts.

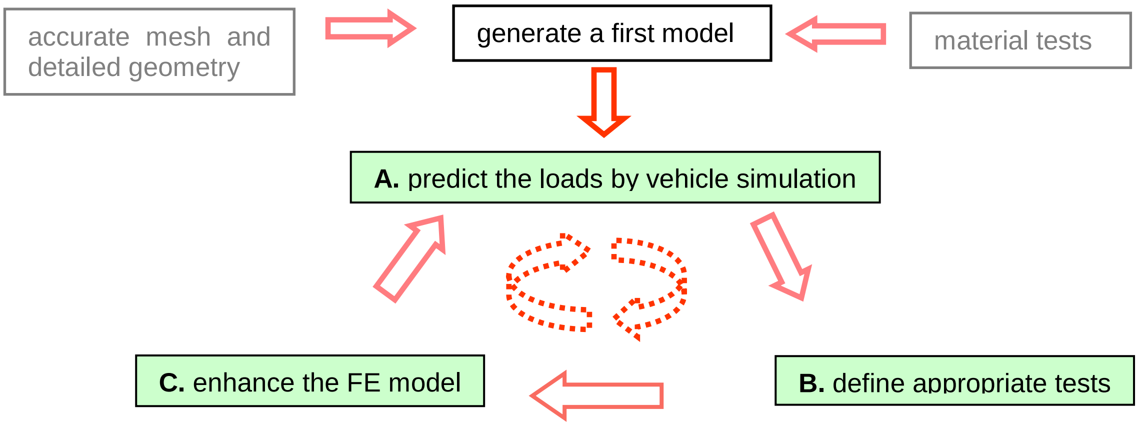

Fig.6: Validation process of FAT and PDB dummy models.

The circle between the sampling Points A, B and C seems to give a never ending process to enhance the model. At the beginning of a Dummy development all three Points are located mainly at the dummy developer until a validation state is reached which can also be used for pre testing or in production of customers. Mainly the first customers are the members of the working group. Then also the experience of the customers are counted to Point A and at the end all findings of all users can be used to enhance the model.

As example for the process loop the shoulder rib tests of the WorldSID 50% are showcased. The first tests are depicted in Fig.7; they are defined to have loading direction for shoulder in different angles.

In the first state of the WorldSID 50% (version v2.0) the ribs are validated by using excessive component test on single ribs and on single partial ribs. One rib of the World SID 50% consists of two Memory Shape rib bands. An outer band and an inner band which are connected at the outside by a clamp. On the inner band a damping material is tied on the inside of the memory shape material for system damping. Validation test are used as depicted in the following picture.

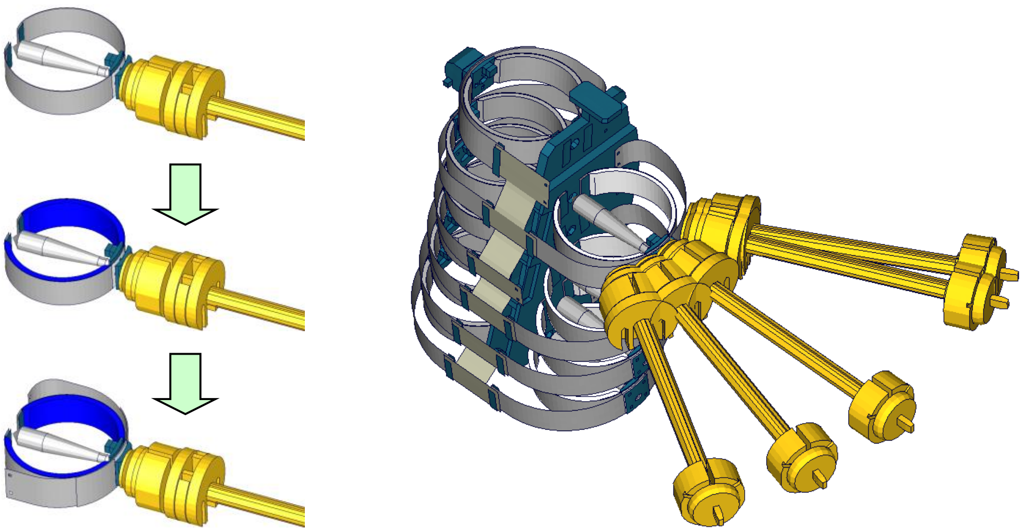

Fig.7: Shoulder rib tests for validation of inner band and complete rib, LEFT; Loading angles of shoulder rib tests, RIGHT.

Validation started with inner rib band without damping material. By using this test for validation, the rib material can be adjusted and the connections of the inner rib band to the torso are defined properly. This can be done without influence of the damping material.

Second test and step for the model validation is the inner band with damping material. Only difference to the previous test is the damping material. All other connections and boundaries are the same. This test is used to adjust the damping behavior in loading and unloading of the damping material and the rib inner band.

The third and last step in the validation program is then the validation of the complete rib, the inner band with damping material and the outer band with all connections. By finalizing this validation process, the ribs for WorldSID v2.0 were validated to the desired tests at this point in time.

Finally for shoulder behavior, the arm as single component is validated with a component test on the arm as depicted in the following figure.

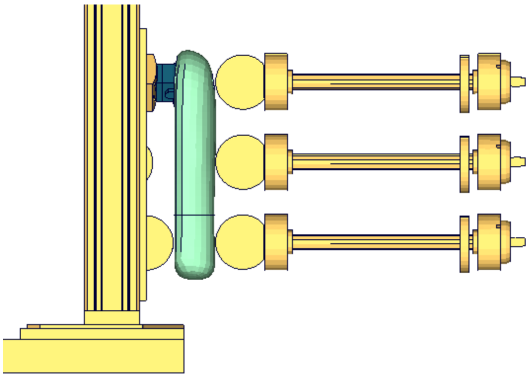

Fig.8: Arm component test of WorldSID 50% (three target positions of pendulum.

The arm is impacted by using three different target positions with different velocities. Due to this the upper and lower arm area is validated and also a bending mode.

In use of the above described validation tests and a final validation of the interaction of the parts, the v2.0 of WorldSID was finalized and was used by the working group and all interested customers world wide.
The experience of all users after about half a year was quite good. But a lot of questions arose about the vertical movement of the shoulder rib. This was observed in many car simulations that the shoulder rib is bending significantly in vertical direction. Therefore no test was available until now.

So the customers predicted loads in the vehicle (Point A. in the validation loop) which are not taken into account in the validation. Due to this, new component tests are defined to assure that the component shoulder/Arm works also fine in vertical direction. The new defined tests are depicted in the following picture.

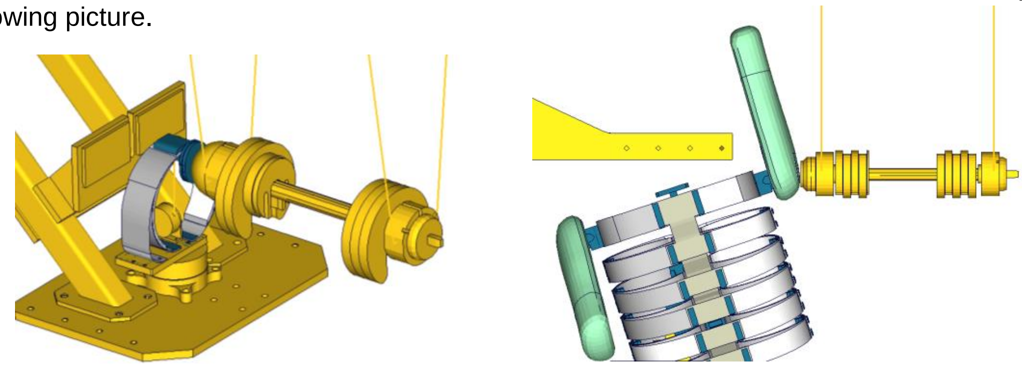

Fig.9: Shoulder rib tests for vertical loading; single rib, LEFT; with arm interaction, RIGHT.

A snapshot of the results of the tests are depicted in the following picture.

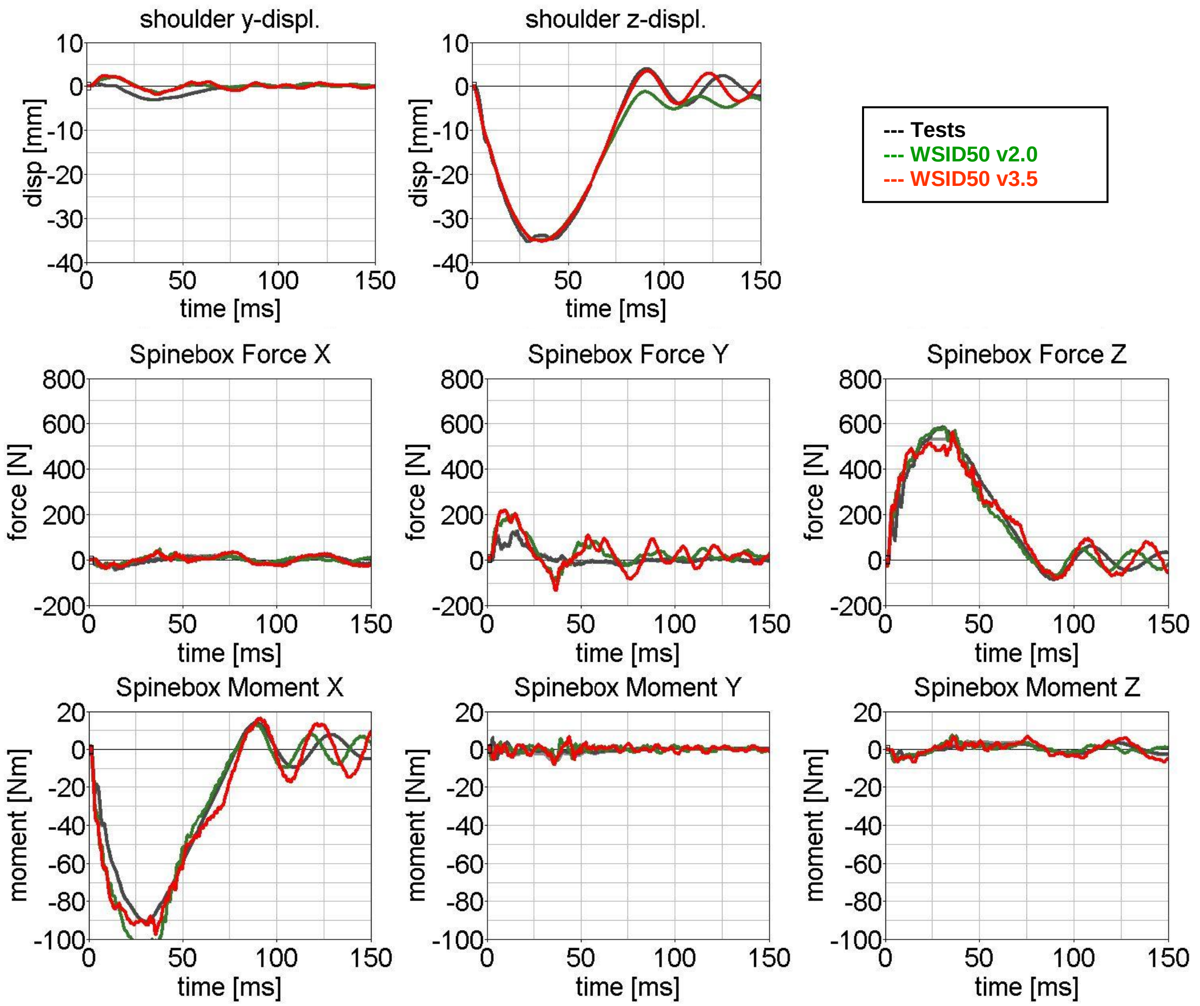

Fig.10: Results of shoulder rib test vertical of WorldSID 50% v2.0 and v3.5

The results are not quite different. Especially shoulder deflection in vertical direction (z-displ. Diagram fist line middle) is very similar. But the moment about the horizontal axis (spine Moment X, diagram third line left) is significantly different in the peak value. It is a difference of 110Nm (v2.0) to 80Nm (v3.5).

Due to the additional test the validation in vertical direction was improved significantly in the displacement – force relationship. The influence of this change in sled test was not visible. Reason for this is the very small vertical loading in sled tests of the shoulder rib.

The improvement is included in the current actual release v3.5 which was released in August 2014. Since this time DYNAmore is still collecting feedback of the model to do further enhancements. We are currently again back in loop A. of the validation process.

From some customers (Jaguar Land Rover) we have collected additional recommendations for improvements, again in the shoulder area. One of these is the exact geometric representation of the 2D IR-TRACCs for rib deflection measurement, in order to capture more realistically the physical contact stops of rib rotation. The enhancements have been started and a picture of the geometric enhancement is shown in Fig. 11.

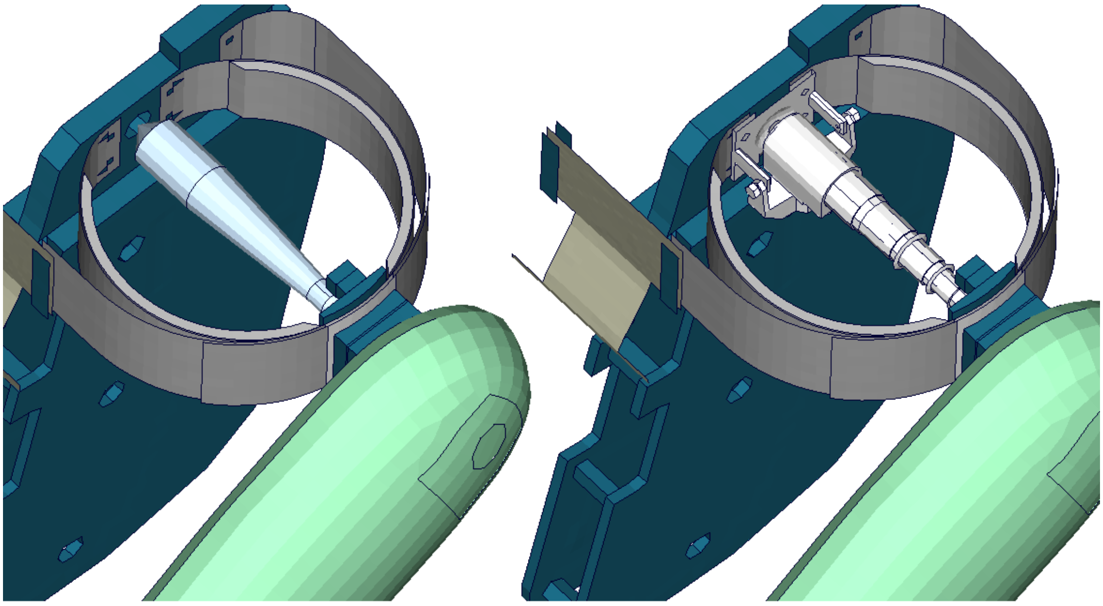

Fig.11: 2D IR-TRACC model of WorldSID 50% LEFT: v3.5; and RIGHT: next release (v4.0).

The range of function for both models is nearly the same. In the current version the rotational stops freedom are defined using joint stiffness cards. In the physical IRTRACC components the stop angles are dependent on the rotations of all other axes, but this effect is neglected by the joint stiffness approach, and can lead in some cases to different rotational stops compared to test.

In the next release of the model the 2D IR-TRACC geometries are represented explicitly, without simplification. The new 2D IR-TRACC model will then also be included into the dummy internal contact. In this way all stop angle possibilities are completely physically modeled.

4 Agile development

In February 2001 software developers met in Utah to discuss lightweight development methods for software. They summarized their ideas about a process to develop software in an iterative way in the Agile Manifesto [1]:

“We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:

- Individuals and interactions over processes and tools working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

That is, while there is value in the items on the right, we value the items on the left more.”

They also formulated the principles behind the Agile Manifesto [1]:

1) Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.

2) Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.

3) Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.

4) Business people and developers must work together daily throughout the project.

5) Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.

6) The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.

7) Working software is the primary measure of progress.

8) Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.

9) Continuous attention to technical excellence and good design enhances agility.

10) Simplicity--the art of maximizing the amount of work not done--is essential.

11) The best architectures, requirements, and designs emerge from self-organizing teams.

12) At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly."

Based on the Manifesto several guidelines and methodologies have been developed lately. Maybe Scrum is the one of the most frequently used method which describes in detail the roles of the different players, the events and the artefacts to develop complex products.

5 Comparison of DYNAmore Process to the Agile Development

The development of the dummy models at the FAT and PDB working groups takes place since more than 2 decades. More details can be found in [2]. During this time the development has been refined several times but many core methods are more or less unchanged. Looking at the principles of the Agile Manifesto many of the ideas can be found in the methods used in the FAT and PDB working groups by the German car manufacturers and the software companies. These methods were applied because they seem to be very suitable to develop the dummy models. Ideas from the authors of the Agile Manifesto were not known to the members of the working group. In the following each of the principles is compared in slight detail with the methods of the dummy model development.

1) The developed models are used by the members of the working group and also by third parties who pay a license fee. Thus, the profitability of each dummy model project was linked to the customer satisfaction and therefore it had a very high priority.

2) The target of all projects was to develop models that will allow a high predictability in simulations of vehicle accidents. This could be judged on the correlation with the test data and on the feedback when the members of the working group were running the models in their car environment. A final judgment about the quality based only on material or component tests is limited. Thus, the requirements for the component and material test correlation were refined based on the observations in the full car simulations. It often occurred that a certain behaviour in a car environment required a high focus on a very good correlation in a specific component test. Changing the requirements was practiced frequently during the projects.

3) The models were delivered for testing after completing the meshing and the material tests, after correlating to a certain set of component tests, and after certain sets of barrier tests. They were further delivered after implementing new LS-DYNA features. The implementing of new data was a continuous process, but the frequency was quarterly or in a later project phase annually. Thus, the frequency is lower than proposed in the Agile Manifesto. One reason for the low frequency is that an evaluation of the model quality takes a lot of time and often test data of full car crashes are needed for a profound judgement.

4) The developers are directly linked to the sales and delivery process. In general our company hierarchy is very flat and we don't have much business people. The idea of the Manifesto is fulfilled in this respect.

5) Since the developing companies are small entities the importance of individuals is high. The daily duties of each developer often reflect their personal preferences and motivation very

well. The cooperation is based on trust rather than on controlling. Again the FAT/PDB project seems to be in-line with the ideas of the Manifest.

6) Most of the work is done by a group of developers who work locally together. The DYNAmore group is located at an office very close or on-site at one of the PDB members. The developers themselves and the customers see each other on a daily basis. The Manifesto points out that this way of cooperating is very effective.

7) The outcome of each project was a finite element input, which you may consider as part of a software. The only measurement of success was the correlation of the models with the test. Revenue or other quantities were not monitored to measure the progress of work. This is in line with the ideas of the Manifesto.

8) During the project the development pace varied significantly during the different development phases. The pace was mainly determined by the testing that was carried out in parallel. Of course the target was a sustainable model, which various customers will use in the future in many simulations. The FAT/PDB projects are in line with the ideas of the Manifesto in terms of the product requirements on the product. In the Manifesto it is proposed to have constant pace in the development. This is not the case in the dummy model projects.

9) Since the dummy models are used by customers who constantly raise their requirements the attention to provide excellent models was very high. Without being one of the technical leaders a world-wide distribution would not have been successful. Thus, the ideas of the Manifesto are well presented in the FAT/PDB projects.

10) The simplicity for the users was important since the models are sometimes used by not extremely well trained people. Therefore, the documentation and the easy-to use capability were important. Simplicity for the internal workflow was also a key to achieve a high development speed. Therefore, all re-occurring steps in the model development are automated.

11) Like it is common practice in smaller companies the teams are self-organized with a very flat hierarchy and a high degree of responsibility for each developer. The developer is also in charge to demonstrate his work in front of the customers and to do parts of the customer support related to dummy models. Thus, the practiced development fits well to the ideas in the Manifesto.

12) Meetings to discuss ways of getting more effective did take place twice a year. In addition, there were meetings at certain stages of the project of the developers and the members of the FAT/PDB to exchange feedback. The effectiveness of the development process was usually one agenda topic among others. Maybe the Manifesto proposes a higher focus on the effectiveness of each step.

6 Summary

The paper describes the development of the dummy models as it is practiced since more than 20 years. During this time many dummy models have been released. Since the results of each project were obviously very successful the same stakeholders launched several subsequent development projects. Some projects targeted to develop new models and others aimed to enhance the quality of an existing model. One of the enhancing projects on the performance of the WS50% model has been presented in this paper in more detail.

The methods applied within the FAT/PDB framework to develop the dummy models have very much in common with the ideas of the Agile Manifesto. Almost all aspects presented in the Manifesto can be observed in the development process as practiced by the developers, the FAT/PDB and the other customers of the models. That the ideas match so well is remarkable because the authors were not familiar with the ideas presented for the development of software.

After publishing the Manifesto the ideas have been formalized and detailed significantly. As results management methods like Scrum are now available to develop software and other products. Within the FAT/PDB the refinement and formalization of the methods did not take place and more informal ways of handling the ideas of the Manifesto are still practiced.

7 Literature

References should be given in the last paragraph of your manuscript. Please use following scheme:

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