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Virtual engineering development in a new car for China

A comparison between six directions modelling with alternative assemblies and Flexset functionality in RD&T

Master's thesis in Product and Production Development

KAREN D C CARBONELL PERALDO
KUN HUANG

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Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

Printed in Sweden by
Chalmers Reproservice
Göteborg, Sweden 2016

ABSTRACT

The challenges the automotive industry has to face nowadays are huge and in order to remain competitive the companies have to find intelligent ways to meet the requirements in sustainability, lower development and production costs, and shorter time to market. The answer to these demands may lay in the use of virtual engineering which is a very promising but still an under development field.

This thesis work deals with testing the capability of virtual engineering by making a comparison between two different ways of using the Robust Design and Tolerancing (RD&T) software, the first one that is implemented at CEVT (China Europe Vehicle Technology) is the six directions positioning system with alternative assemblies that will be tested against the new Flexset functionality.

Since CEVT is a quite new company in the automotive industry it is also of interest to map out the current working procedure during the product development process of the body in white and to present a model that reflects this one, as well as to find possible improvement areas.

The results of this thesis work have been satisfactory since all the goals and tasks have been achieved. The Flexset functionality has been successfully tested in a usability perspective and several advantages in comparison with alternative assemblies have been discussed. The Flexset functionality is ready to be incorporated to the daily routines of the Dimensional Management department at CEVT. Also a conceptual working procedure model of their current product development process of body in white has been presented; and several problems have been detected and discussed that hopefully will help to find better solutions and to develop a common working procedure process that applies to all CEVT employees.

This report aims partly to be a pioneer in the geometry assurance field, especially regarding the new Flexset functionality since no writing work is done in this matter, and an instruction of their use will be found in the Appendix C. The thesis work also aims to contribute with CEVT by providing them a model of their current working procedure, pointing out their weaknesses and suggest possible solutions in order to improve their product development process.

PREFACE & ACKNOWLEDGEMENTS

The following report is a compilation of the master's thesis work that the authors have done during the spring 2016 at China Europe Vehicle Technology (CEVT) and at the department of Product and Production Development at Chalmers University of Technology in Gothenburg.

The authors are obligated to all the people that in some way have collaborated to make this project possible, specially to our examiner Lars Lindkvist for his good advises and commitment to the development of this master's thesis, as well as to our supervisors Peter Edholm from PE Geometry and Claes Hammarson from CEVT for their support and guidance.

This master's thesis could not be a reality without the mentoring of the talented PE Geometry's consulters Andreas Stenlund and Kim Dalkarls**,** thank you for your time and sharing your competence and experience with us.

Special thanks go to our interviewees Lars Ljunggren, Henrik Svantesson, Paul Wilson**,** Kenneth Kajsjö and Henrik Persson, thank you all for your invaluable contribution to the understanding of the working procedure process at CEVT.

Last but not least, a great thanks go to our families how have supported us with their love and understanding during this journey.

Gothenburg, October 2016

Karen and Kun

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1 INTRODUCTION

The future for the automotive industry and in special for Geely vehicles may lay in the use of virtual engineering to successfully satisfy the new demands on sustainability, lower development cost and shortened time to market.

Nowadays different tools are being used to accomplish these goals and some of them are still under development process. At CEVT the CAT tool RD&T (Robust Design &Tolerancing) is being used to develop new cars for Geely and their new brand Lynk & Co.

The focus of this master's thesis shall be put in robustness analysis and variation simulation of body in white assembly at CEVT and also in mapping out the company's working procedure between the actors involved in this development process. The delimitations of the project are going to be clear and a proven formal methodology for product development is going to be applied and will be followed during the entire process.

1.1 Topic

This master's thesis is aimed to test the capability of virtual engineering in terms of geometry assurance by using the software RD&T (Robust Design &Tolerancing) for simulations of body in white models of Geely vehicles. Both current used software and the new functionality Flexset are going to be tested. This is going to be made in order to find an optimal solution to be implemented at CEVT and suggest future development potentials.

For this purpose a usability comparison between the current used six directions positioning system with alternative assemblies against the new Flexset functionality is going to be performed by building a RD&T model of a specific case of body in white of a new Lynk & Co car, and different kinds of calculation analysis would be run in order to compare the results on robustness and variation of these two ways of modelling.

Since the company is quite new, it is also of interest to map out how the current working procedure, between the involved departments at the company looks like during the development process, who are the actors and their interrelationships, which other factors or inputs could affect this process, as well as to clarify if any sustainability aspects are being taken into consideration.

In order to accomplish this goal a conceptual working procedure model of the product development process of body in white is going to be developed by using a formal methodology which will be presented later on. This journey to elaborate the model will help to point out latent improvement areas that will be presented in order to contribute to raise and solve problems occurring during the product development process.

1.2 Goals/objectives

Expected outcome of the study:

- A theoretical model describing the working procedures of today.
- A description of the desired improved situation.
- Suggestion of methods and tools that can be adopted as a solution.

- Identification of improvement potentials in terms of efficiency, accuracy and information loss.

- Evaluation of the benefits of connecting the product development and the production process in an early phase.

1.3 Tasks

The following tasks are going to be performed during the course of this project:

- Learn the basics of geometry assurance work (methods, tools, philosophies) by self-studies and mentoring.

- Learn the basics of a body in white assembly process.

- Build simulation models of a body in white process in RD&T. The case would be provided by CEVT in agreement with the authors.

- Map out and evaluate the current working procedure at the company during the product development process of body in white.

- Detect and discuss improvement areas in the working procedure process.

- Evaluation and analysis of the results.

- Discussion about the capability of suggested methods in production engineering perspective (manufacturing capability, time balancing, quality reliability, data flow from production line, preventive maintenance).

- Test the new RD&T functionality Flexset and make and present an instruction for the CEVT's Dimensional Management department team members to show them how does Flexset work and how they can incorporate this new functionality to their daily work.

1.4 Stakeholders

This master's thesis was carried out from January 20th to June 22th 2016 at the CEVT's Dimensional Management department engineering office in Lindholmen and in close collaboration with PE Geometry's specialist office located at Chalmers Science Park, both situated in Gothenburg, Sweden.

China Europe Vehicle Technology (CEVT) is a rapidly growing automotive engineering business in Gothenburg with more than 1700 engineers employed in Sweden and China during the last 2.5 years. CEVT is owned by Geely and develops future platforms for both Lynk & Co and Volvo Cars.

PE Geometry is a specialist company within geometry assurance and holds the largest competence as well as the largest group of geometry assurance specialists in Sweden. The expertise of the employees is sought after in different lines of businesses, both in Sweden and worldwide.

Figure 1: CEVT and PE-Geometry logotypes

The following stakeholders were supporting the authors during this journey:

Examiner:

Professor Lars Lindkvist, Chalmers University of Technology

Supervisors:

Peter Edholm from PE Geometry and industrial PhD is the academic supervisor from Chalmers and in charge of the technical support in RD&T and geometry assurance, modelling support etc.

Claes Hammarson from CEVT is the industrial supervisor and provides product knowledge, CAD models and the contacts necessary to perform this master's thesis.

1.5 Background

A body in white is a complex assembly of around 350 parts. Many times problems show in the manufacturing phase when parts do not fit together and it is very time-consuming and expensive to try to solve these problems during production or even worse to go back to the product development phase to fix these problems. This is why it is so important to incorporate the production demands early in the product development process in order to predict and solve these problems before they appear during manufacturing.

New demands on sustainability, economy and time-to market require another kind of solutions. Virtual engineering may be the answer to these problematic issues and the future for the automotive industry. In order to secure a high quality, virtual tools and methods are getting increasingly important to ensure robust solutions as early as possible in the product realization process.

During the product development process at CEVT, virtual models of the body in white are created and these can be analyzed at different stages with focus on robustness analysis and variation simulation. These models are later on used in the production phase. This work should combine the CAT knowledge with real production line requirements to solve possible manufacturing problems. To accomplish this goal it is very important to have a good communication and collaboration between different departments in the company and China.

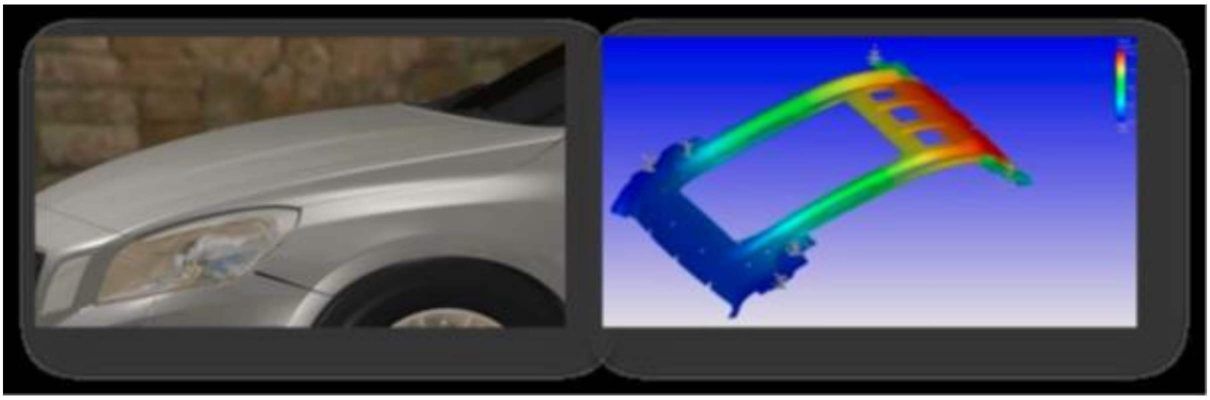


Figure 2: Example of the use of the RD&T software

1.6 Delimitation

- This master's thesis is going to be focus on the RD&T model of body in white in a specific project.
- Only a part of the body in white assembly process is going to be simulated.
- The chosen case is the body side inner for a sedan model of a new Lynk & Co car. The case would be explained in detail in chapter 3.4.1.
- In this project, only one improvement solution in terms of usability will be tested, which is the new functionality Flexset in RD&T.
- Complaint modelling is not going to be tested in the simulations.
- Only the departments involved in this development process would be included in the working procedure analysis.
- According to the boundaries in this project, the working procedure model will only cover the product development process of body in white and would not be tested because of the time factor.
- Only the environmental and social sustainability in terms of ergonomics are going to be studied, the economic sustainability is not going to be included.

2 LITERATURE REVIEW

It is compelling for the authors to have an overview about the existing literature in RD&T, rigid and non-rigid models, body in white and other useful material. This chapter will cover a study of what kind of work is already been done in these matters.

It should be remarked that most of the existing work is been done in Sweden which is a leading nation regarding geometry assurance in the automotive industry. Most of the acquired literature consists on published scientific articles and papers, and conference material but even a considerable amount of Master and Doctoral theses has been founded. On the other hand is uncommon to find books that cover these topics. PE Geometry in Gothenburg offers specialized education and had developed their own material to teach their clients the use and understanding of the RD&T software, but this material is confidential and not open for the public. The authors had access to this material which was crucial for the successful development of this master's thesis.

The work founded covers rigid and non-rigid variation simulations, assemblies, geometrical variation, robustness, etc. These can be encountered in form of scientific articles and papers most of them written by the creators of the software and other researchers in this field.

Books that cover RD&T are difficult to find, on the other hand it is possible to find books or manuals that cover more general topics like technical drawing and tolerancing.

A quite considerable amount of Master and Doctoral Theses covering rigid and non-rigid variation simulations in the automotive or aerospace industry can be founded.

For those interested in learning more about RD&T, geometry education courses which include printed material, supplied by PE Geometry, covering both general and more specialized instructions can be bought, otherwise it is confidential material.

Manuals are included in the RD&T software and are the primary tool for potential users.

Lecture material from university classes could be quite useful as well but can only be accessed by students and university staff.

No material regarding the new Flexset functionality in RD&T has been founded. The explanation for this is that the function is quite new and still under development. Hopefully this master's thesis would provide a little help for future Flexset users in form of an instruction/manual.

3 METHODOLOGY

The methods used to accomplish the goals and tasks of this master's thesis are described and explained in the following chapter. The corresponding implementation and analysis of the chosen methodology will be presented in Chapter 5.

After careful consideration it was decided to use the method for product development presented by Ulrich and Eppinger [1]. The generic process includes a sequence of six phases as follows:

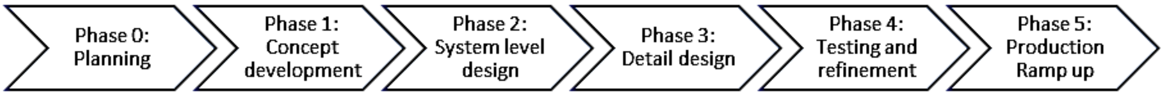


Figure 3: The product development process by Ulrich and Eppinger [1]

Of these ones, only phase 1 would be applied to this study. It should be pointed out that the chosen methodology has been adapted to develop a process and not a physical product.
According to Ulrich and Eppinger the concept development phase integrates the following steps:

- Identifying customer needs
- Product specifications
- Concept generation
- Concept selection
- Concept testing

A simplified picture of the chosen methodology to follow, which is adapted to this study, is presented in the figure below:

Figure 4: Concept Development Phase

The entirely methodology, including the different techniques used in each step of this process, is resumed in Figure 5. Each method is going to be presented in the following sections.

Figure 5: Chosen methodology

3.1 Self-studies

In order to get prepared to execute this master's thesis, it was necessary to cover some fields both in theory and practice before getting the project started. These fields are presented in chapter 4: Frame of references.

Besides the self-studies, a number of presentations and/or mentoring sections were performed with experts in each area that supplied huge help through this process.

3.2 Identifying customer needs

Every successful product development process should put the customer on focus. First of all, it is important to identify who is the customer. The users of RD&T program at Dimensional Management department at CEVT are the direct customers, but even people from other departments, who are involved in this process, would get beneficiated with the results of this master thesis and are considered as customers too.

Several methods were used in order to identify customer needs, problems or improvement areas and to clarify the working procedure. These methods would be explained in the following sections.

3.2.1 Interviews

Since CEVT is a quite new company in Sweden with employees that have backgrounds from different automotive companies and its first project has not been completed yet, there is still not a clear picture of how this complex process works. In order to have a better basic understanding of the structure of the current working procedure, it was decided to perform some interviews of qualitative approach with different departments at the company. More detail information about the interviews would be presented in Chapter 5: Implementation and Analysis.

3.2.2 Observation

Another way to identify customer needs is through observation of their daily work. This can be performed passively just by observing their working procedure or with interaction, which means by working together with the customers.

3.2.2.1 Visit to Volvo factory

In order to get a better understanding of the body in white assembly process in a real production line, and if possible to capture some other requirements the customer would have to take into consideration during their working process, a visit to A-factory at Volvo Car facilities in Gothenburg was performed.

3.2.3 Interpretation of raw data

The data acquired from interviews and observations has to be processed in a methodical way in order to identify customer needs and problems before the working procedure can be established. Two methods are going to be used and explained in the next sections: the customer data template and the KJ method.

3.2.3.1 Customer data template

In the customer data template, customer needs are translated from written customer statements obtained from interviews or observations [1]. Besides the customer needs, it is as well of interest to identify problems and build an understanding of the working procedure using the same template, so the template has been adapted to the needs of this project and two more columns has been added for those specific matters. In general this template works well even if the product is virtual and not physical.

3.2.3.2 KJ method

This method is going to be used to continue analyzing the data from the customer data template. The KJ method is a group consensus process using affinity charts developed by the Japanese anthropologist Jiro Kawakita. This process is extended used in American and Japanese applications. It consists of four steps: label making, label grouping, chart making and explanation. In practice, labels such as post-it notes with text from the collected data are made in order to be grouped along one common denominator. Through this process, the labels are organized by content and not along preconceptions in different categories. Finally these are analyzed in a kinship chart [2].

3.2.4 Establish hierarchy and importance of the needs

Finally the customer needs have to be arranged in hierarchy. Several rearrangements can be considered before deciding the one that reflects the needs better. The next step is to give the needs numerical importance weighting. This weighting is going to be required in the next step of the methodology. A reflection on the results and the process at this time should be made before going forward to the next step.

3.2.4.1 AIM analysis

A further development of the KJ method, the AIM analysis is going to be used to continue analyzing the data. The Affinity Interrelationship Method (AIM) [3] is based on the KJ method and was developed by Professor Shiba Kojito. The method aims to secure the quality of qualitative data and it is extendedly used in quality management fields. We are not going to follow all the steps of the method since we already have our data from the customer data template and the KJ method. We will proceed directly to the grouping and will adjust the method according to our own criteria to establish a hierarchy in importance order.

3.3 Process specification

A process specification is a precise description of what the product, or process in this case, can do, it establishes target requirements and is driven by customer needs [1]. The products in this study are a theoretical model of the current working procedure and a RD&T model of a specific work case.

It has to be remarked that the process specification for this project is not going to have units or values since no quantitative data has been collected and not competitive benchmarking information is going to be collected or used as the Ulrich and Eppinger [1] method suggests for the process specification. The confidential character of the product as well as the uniqueness of this project makes difficult finding relevant benchmarking information at this point. The specification is going to be used during the concept generation process to establish the working procedure and identify problems or possible improvement areas.

3.4 Concept generation

The general procedure to generate a concept according to Ulrich and Eppinger [1] consists of the following steps:

1. Clarify the problem
2. Search externally
3. Search internally
4. Explore systematically
5. Reflect on the results and the process

Each one of these steps is going to be applied when generating the different concepts in this project, making adjustments to fit each concept. It should be pointed out at the externally search is not applicable in the generation of these concepts because of the confidential character of each one, all the necessary information can and would be found internally.

3.4.1 Work case

The work case was decided after studying the body in white and in agreement with the Dimensional Management department. After careful consideration, a case was chosen to start developing the working model in RD&T. In order to restrict the work in a realistic and reasonable frame considering the limited time for the completion of this master's thesis, and in accordance with the delimitations of this study, it was decided only to consider the body side panel inner of the body in white for a specific Geely sedan model, which is still in conception phase and should be ready to launch in 2018. Since the model is not on the market yet, the name would be kept confidential in this report.

The chosen work case can be found in Chapter 5.3.1.

3.4.2 Modelling in RD&T

The software used for geometry assurance calculations in CEVT is RD&T. In general this program allows the developer to choose the way of modelling using the same software version. Modelling in six directions positioning system, with alternative assemblies and Flexset are going to be presented.

3.4.2.1 Modelling with six directions positioning system

All parts are in general modelled using six directions positioning system which gives more freedom than the 3-2-1 positioning system, since each of the six directions points can have its own positioning plane [4]. Starting from this six directions positioning system, it can be chosen if continuing modelling using Flexset function or alternative assemblies.

3.4.2.2 Modelling in Flexset functionality

Based on the chosen work case the Flexset functionality is going to be applied to the working model in RD&T. All the necessary information can be found in different documents at CEVT's intranet and Teamcenter.

3.4.2.3 Modelling in alternative assemblies

In order to make a comparison in usability another model is going to be created in RD&T using alternative assemblies in six directions positioning system. For this model it is important to reuse the same locating schemes, tolerances and measures as for the Flexset model. Once again all the necessary information can be located in different documents at CEVT's intranet and Teamcenter.

3.4.3 Working procedure

Another concept to be developed is the current working procedure model for product development, involving several departments. This is going to be generated using the results from the customer data template, KJ and AIM analysis and process specifications, and would be eventually completed using information from the CEVT intranet.

3.4.4 Identifying improvement potentials

From the previous methods used in section 3.2 and 3.3, a number of problems should be able to be identified, discussed and possible solutions could be suggested. In chapter 5.3.4, the identified problems regarding the current working procedure as well as the problems detected in the RD&T models would be presented in detail.

3.4.5 Sustainability

As it has being pointed out before, it is also of interest to find out if any aspects regarding sustainability are being taken into consideration during the product development process.

There are basically three kinds of sustainability, see Figure 6 [5]. As it was mentioned in the delimitations of this project, only the environmental and social sustainability in terms of ergonomics are going to be studied, the economic sustainability is not going to be included. The methods used for this subject are explained in sections 3.2 and 3.3.

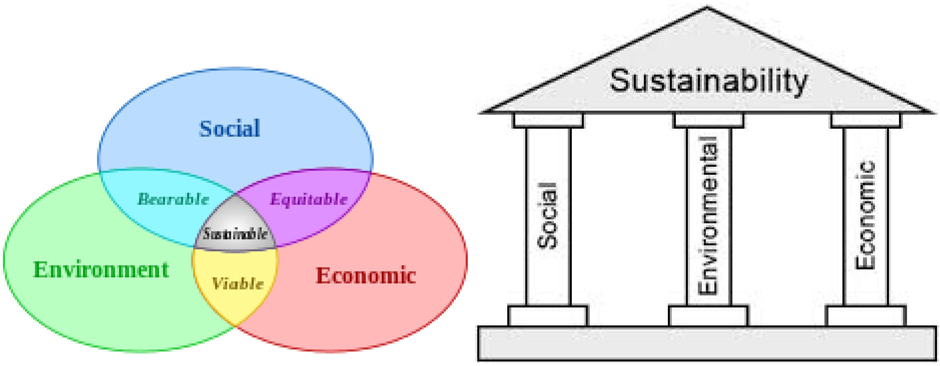


Figure 6: Three pillars of sustainability [5]

3.5 Concept selection

Since the final product for this master's thesis differs from a traditional physical product that is generated by selecting among a lot of different concepts, the previous analyses will result in a conceptual model that corresponds to the current working procedure for product development of body in white at CEVT based on the methods presented before. No additional concept selection would be applied at this point.

For the RD&T models that will be generated according to chapter 3.4 no further concept selection is required; the authors would proceed directly to the concept testing part of the methodology.

3.6 Concept testing

In this section the two RD&T models are going to be tested against each other in terms of capability and usability and the results will be presented.

Because of the time factor, the models are only going to be tested by the authors.

The conceptual working procedure model is not going to be tested; once again because of the time factor, but for a further development to validate the results of the presented model surveys and focus group are two methods that are strongly suggested to be used.

4 FRAME OF REFERENCES

In the following sections the frame of references for this master's thesis is going to be presented. Each section is of great importance and prepares the authors for the successful completion of the previous presented goals and tasks of this project.

4.1 Datum Target System (DTS)

The theoretical framework for DTS presented in this section is based on the geometry education provided by PE Geometry [6].

DTS uses coordinate systems and 3-2-1 principle to define strategically located points on a part in order to fix it in a repeatable unambiguous position with low variety. It uses the same position for every specific part in all processes from single part to final assembly.

Support points can be used to provide full support to an unstable body and are numbered upwards. Arising unnecessary stresses should be avoided. The most suitable feature should be chosen regarding robustness, repeatability and cost considering all stakeholders. To enable common understanding and improve traceability from single part to the entire production process, the basic idea is to use the same systematically and consistently placed initial datum targets, which are retained as long as needed and deleted as the process carries on.

There are several reasons to use DTS; the most important ones are listed below.

- DTS helps to assure quality of products.
- Make possible common understanding between different roles.
- Decrease the production time in order to increase competitiveness and enables the use of Statistical Process Control to monitor the production.
- Reduce development time by securing the geometrical quality of the product and resulting in shorter time to market and lower costs.
- Enable efficient developing and manufacturing of complex products.
- DTS is an information carrier along the project time and across the project team.
- Geometrical assurance is a prerequisite for modularization. Modularization ensures that corrective actions are made before the problem appears in the production process.
- Predict the geometrical result of a product in an early stage, allowing design changes to be made at the beginning of the project which could lead to reduced costs.

4.1.1 3-2-1 principle

The 3-2-1 principle is used in DTS to define the position and supports parts by locking the body in six points defined by six degrees of freedom.

The first three points lock two rotations and one translation that are numbered 1-3, the second two lock one rotation and one translation that are numbered 4-5, while the last one locks the least translation numbered as 6. Figure 5 shows 3-2-1 positioning system which locks all possible movements.

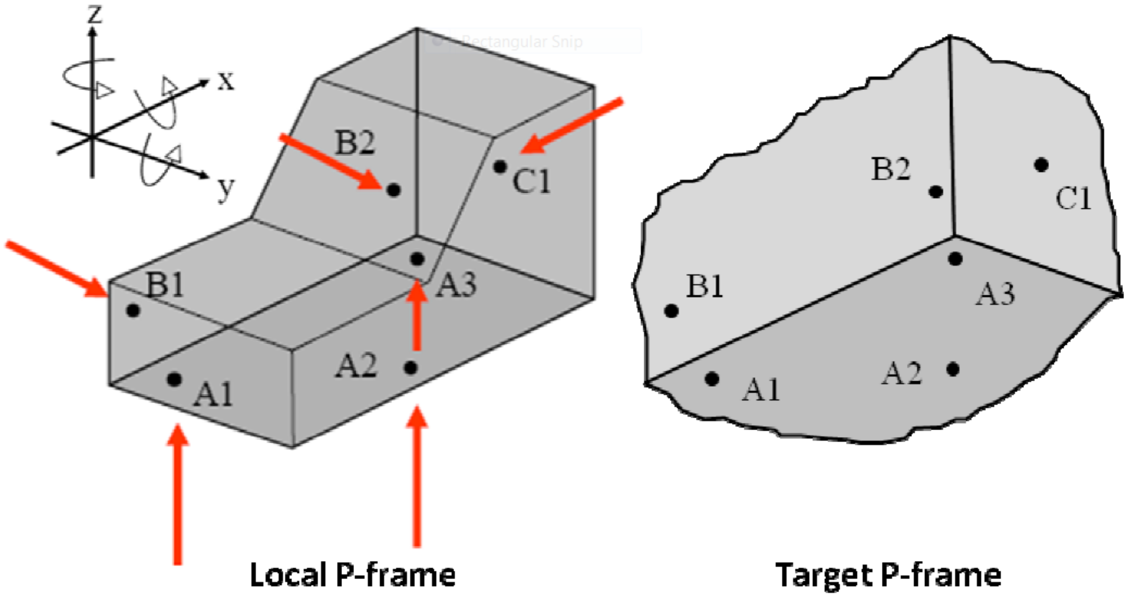


Figure 7: 3-2-1 positioning system

4.1.2 Application of DTS

DTS is the basis for tolerancing, measuring, assembly and root cause analysis. The unambiguous functional tolerancing of a part to the surrounding is ensured by DTS. The nominal "zero" for the parts and other feature tolerances (non-nominal) are defined in accordance to this zero as defined by DTS.

Position of parts will be exactly the same every time in every process. The functional datum targets when fixing, should be placed where datum targets are. Tolerance requirements would be relative to DTS while all deviations are relative to the coordinate system.

Using same geometrical basis of datum targets could shorten tolerance chain and redundant information. Also it could avoid useless assembly caused by failure positioning. The red thread (connecting datum targets from all parts in assemblies and subassemblies) could be followed upwards and downwards allowing the predictions (tolerance chain calculations) to be used for root cause analysis.

Every stage in manufacturing process has to use datum targets, so positioning of datum targets should be considered carefully. Decisions should be made by gathering expertise from design to manufacturing fields. Datum targets could not be added in assemblies if not been presented in the level below.

Datum target positions control the geometrical robustness. Small distances in between datum targets means more sensitive to variation. Datum targets should be spread as much as possible considering the geometry of the parts to improve robustness, which could minimize geometrical variation in order to eliminate extra costs.

DTS is strictly connected with part tolerances, so changes in DTS require changes in tolerance levels also. Using DTS as basis for measuring could give direct connection to requirements from each production step to the final complete product. Process could be well controlled and geometrically assured before entering next process step.

Consequently using DTS enables a structured distribution of tolerances on product and process. Overall requirements could be break down to tolerances on sub-assemblies and single parts.

The “golden rule” is to always re-use datum targets from previous assembly parts. This enables to maintain the exact locations in each assembly step and as a consequence, a good process control. Customer driven requirements on component level at the supplier are ensured by DTS. It secures the gap of the vehicle surface in production.

4.2 Tolerancing

This theoretical frame about tolerancing is based in the geometry education provided by PE Geometry [7] and the Kompedium Ritteknik [8].

4.2.1 System of fits

This system provides tolerances and deviations for plain work pieces and is aimed to be used for fits between simple geometrical shaped objects.

There are basically used three kinds of fits between holes and shafts:

- Clearance fit: upper limit of shaft is smaller than the lower limit of hole.
- Transition fit: in between.
- Interference fit: lower limit of shaft is bigger than the upper limit of hole.

4.2.2 Datum

The datum features (capital letters) are used to restrict the transition and rotation of the part when placed in fixtures.

Order of datum is important. The 3-2-1 principle is applied for primary, secondary and tertiary datum in that order. The primary datum is aligned first and so on. Different order in datum gives different results. The order tells how to set up the part in order to machine or inspect a specific feature.

Datum features and datum are not the same. To clarify the concept, see Figure 8 [9].

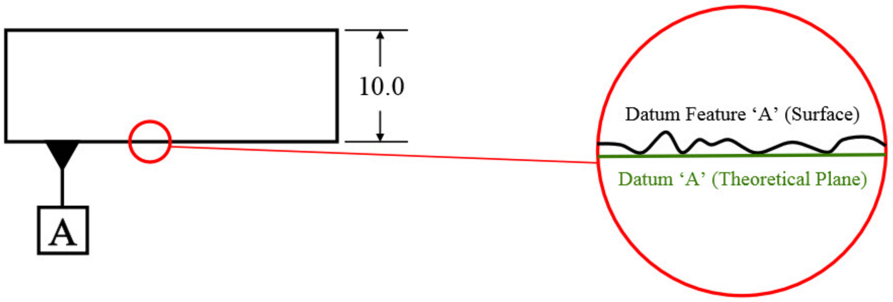


Figure 8: Datum Features ≠ Datum [9]

Datum targets are specified as regions of the datum feature, used for locating the part in a fixture. A datum target can be used to specify a point, line, or area on a part to establish a datum. For example by evaluating datum targets A1, A2 and A3, the primary datum A could be determined. Same principle is used for secondary and tertiary datum.

Commonly in manufacturing and design, "datum" could cover everything just for simplicity.

4.2.3 Volvo Car Corporation's master location system

VCC's master location system is used to point out how the part could be positioned in the coordinate system. The main purpose of it is to systematically and consistently use points to increase traceability in the production. Also it is the base of tolerancing and inspection.

Master location points are given sequentially, similar to datum targets. Numbers 1 - 6 are used for master location points of main- and interface systems. For example, X1, X2 and X3 are the three master location points along the direction of the coordinate that using 3 points. Number 7 - n are used for supports.

The difference between master location points and datum targets is that datum targets are placed for surface only, while master location points are placed for parts, for example body frame. The position of master location points of each master location system in the start phase need to be fully considered because in the assembly, only the existing master points would be reused instead of creating new master points.

It is not allowed to put tolerances to a master location system in a main system because the master location points are always zero and no deformation is present. But it is possible to put tolerances on the support locators from point No.7 and so on but some demands have to be specified like unclamped. Part would start deforming at support locators if it not fully clamped. In an interface system or subsystem, it is allowed to put relevant tolerances in order to get smaller demands in comparison or in relation to the main system.

4.2.4 Tolerances

In order to define the geometrical correctness of a feature the use of tolerances is required.

The tolerances are divided basically in four groups: Form, orientation, location and round out. Profile tolerances could be of form and/or orientation.

The most used tolerances and their symbols are presented in Figure 9 [10].

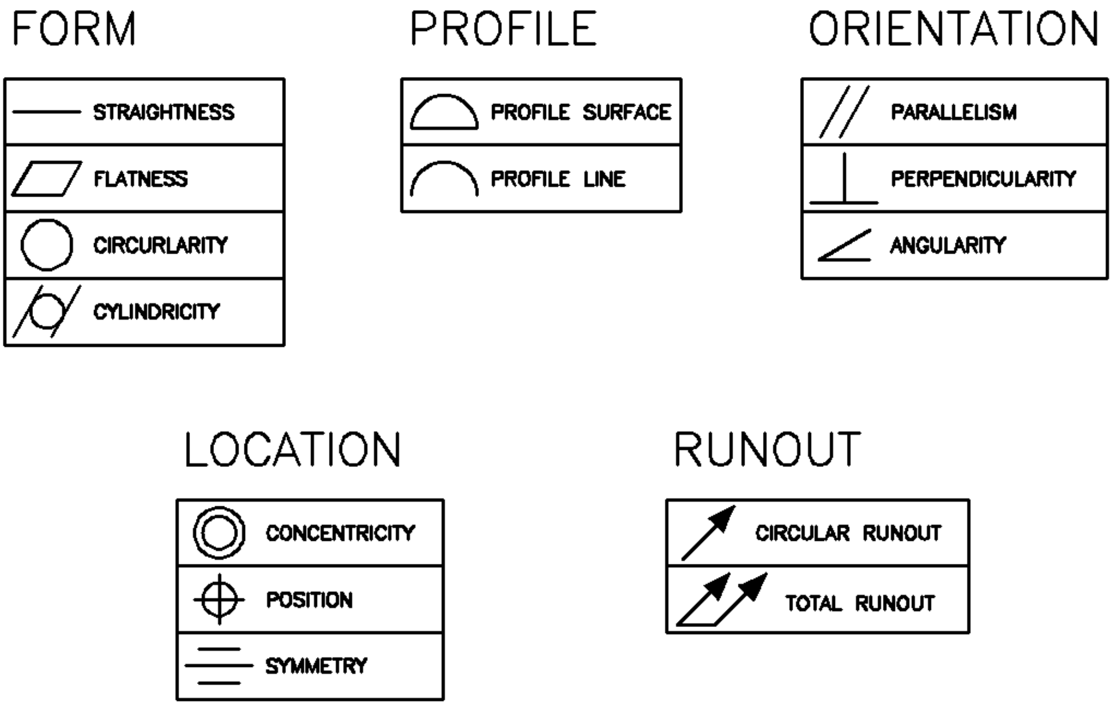


Figure 9: Tolerances [10]

Run-out tolerances are applied only to rotated features (a complete or a part of a revolution around the datum).

To define shape function, sometimes it is needed to combine form, orientation and location tolerances together to ensure accuracy. For example, for a surface, it is theoretically enough to put a profile of surface in orientation and location to define the surface position, but it is also needed to define the flatness in order to keep the surface flat. It is not a repetition or redundant indication, but is for completely defining the shape function. In the case of a perpendicular pin to a surface, a cylindricity requirement cannot be replaced only with a circularity demand. It would require even a straightness demand to be equivalent.

There are many ways to set the tolerances according to customer’s requirements and the machinery availability. To choose the suitable datum of a part, there are a lot of parameters that need to be considered, such as material property and variance. For example, tension of sheet metal could be resulted if putting datum in the surface instead of holes. The datum needs to be put in the area with the least variance because it would have relation to every other surface or part. Otherwise, it would cause more or bigger variance in other area. Also the holistic view is important. The position of datum should result in the least variance or influence to the other area.

4.2.5 Maximum Material and Least Material Principle

Maximum material requirement (MMR), symbol Ⓜ, describes the condition of a feature or part where the maximum amount of material (volume/size) exists within its dimensional tolerance. It allows an increase in the geometrical tolerance when the feature deviates from its maximum material condition (in the direction of the least material condition).

Indication is placed after the tolerance value, the datum or both.

Figure 10 [11] shows an example of how MMR, alternative LMR can be represented in a similar drawing.

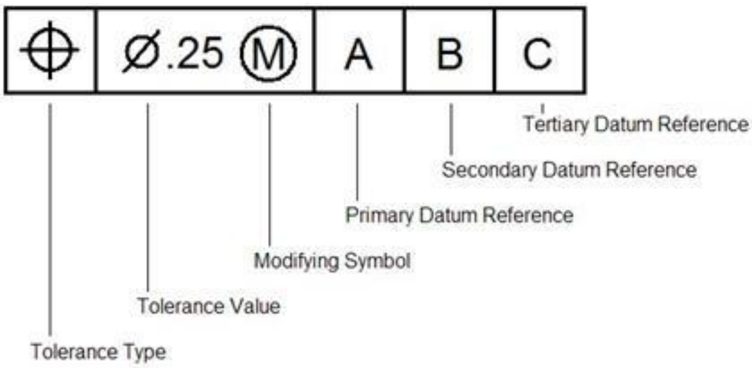


Figure 10: Maximum Material or Least Material Principle [11]

Least material requirement (LMR), symbol Ⓛ, allows an increase in the geometrical tolerance when the feature deviates from its least material condition (in the direction of the maximum material condition). Indication is the same as above.

4.2.6 Surface structure

All surfaces have defects due to different manufacturing methods. These defects have different wavelength and amplitude. Shortwave defects are called surface roughness, more regular, while long wave defects are called deviations. The ones in between are called waviness.

Surface Roughness is quantified by the deviations in the normal direction from real surface to the theoretical surface.

Figure 11 [12] and Figure 12 [13] show some symbols for representing the surface structure in drawings and the surface pattern orientation respectively.

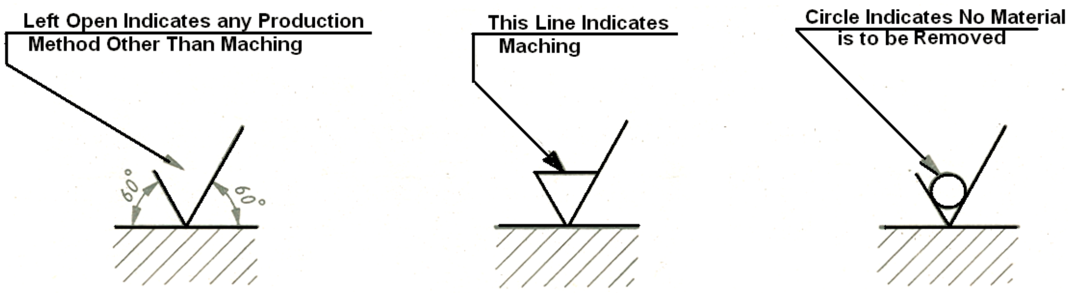


Figure 11: Symbols for surface structure [12]

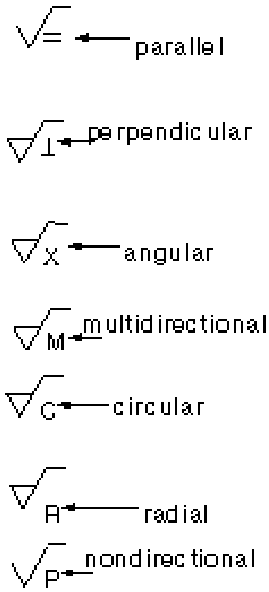


Figure 12: Symbols for surface pattern orientation [13]

4.3 RD&T

The theoretical framework for RD&T presented in this section is based on the geometry education manuals provided by PE Geometry [14], [15].

The developing of the Computer Aid Tolerancing (CAT) software RD&T was started in 1998 by Lars Lindkvist and Rikard Söderberg [16] both from the department of Production and Product Development at Chalmers University of Technology. RD&T with full name Robust Design and Tolerancing is based on the geometrical robust design. This program is a tool to implement robust design in product development phase in a product lifecycle, and it could perform stability, variation and contribution analysis based on the mathematical simulations by Monte Carlo method [17].

RD&T is implemented in the early stage of product development process to handle the requirements of design quality, such as controlling gap and flush in the surface of product and suggest robust solutions. This program could also be used in the later stage to verify the requirements of quality are fulfilled with the inspection data [18].

4.3.1 Six directions positioning system

Positioning system is the basic function of RD&T to position the parts according to the realistic requirements from manufacturing and design. There are several approaches to use when choosing the positioning system in RD&T. In general, it is divided into orthogonal system and non-orthogonal system.

However, the six directions positioning system, which belong to the non-orthogonal systems, is the most used choice in CEVT current work. This positioning system uses six locating points on the local parts that come with six target points on the mating parts. In positioning system defining, the mating parts need to be specified, as well as the directions of the 12 points, both on the local and target. It follows the 3-2-1 locating principle that has been stated before.

The benefit of this six directions positioning system is that the directions of each plane is not forced to be perpendicular to each other. Meanwhile, it could be used as orthogonal system or non-orthogonal system depending on the requirements of the users.

4.3.2 Analysis methods

There are several methods that could be used when analyzing geometry in RD&T, such as stability, variation and contribution analysis. Each specific analysis method would be introduced in the following sections.

4.3.2.1 Stability analysis

There are no requirements for tolerances and measurements in RD&T to perform a stability analysis. Once the model is created with geometry and master locating points, it is possible to run stability analysis to check if the model is robust enough. This analysis is performed based on adding small unit disturbances in every locator of the model. Color-coding can be realized as a virtualization tool in RD&T to evaluate the robustness of the model. In this analysis, color from blue to red represents most stable to the least [4]. An example is given in Figure 13.

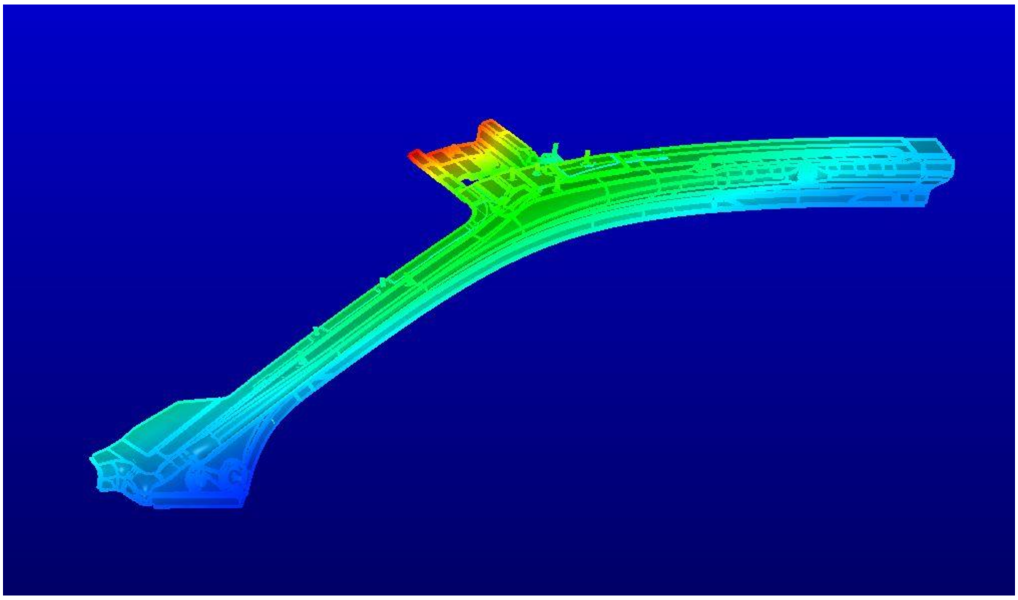


Figure 13: Color coded stability analysis of Upper A-Pillar both Inner and Reinf

4.3.2.2 Variation analysis

In variation analysis, tolerances and measurements in the model are required. This analysis is based on Monte Carlo simulation in order to get variation result for all the measurements that have been defined in the model. This analysis displays range of variation, standard deviation and corrected capability. In this project, variation analysis has been used very often to compare the 8 standard deviation result of specific measuring points in different positioning systems [4]. An example is displayed in the Figure 14. From this analysis, the distribution of each measurement is presented to visualize the result.

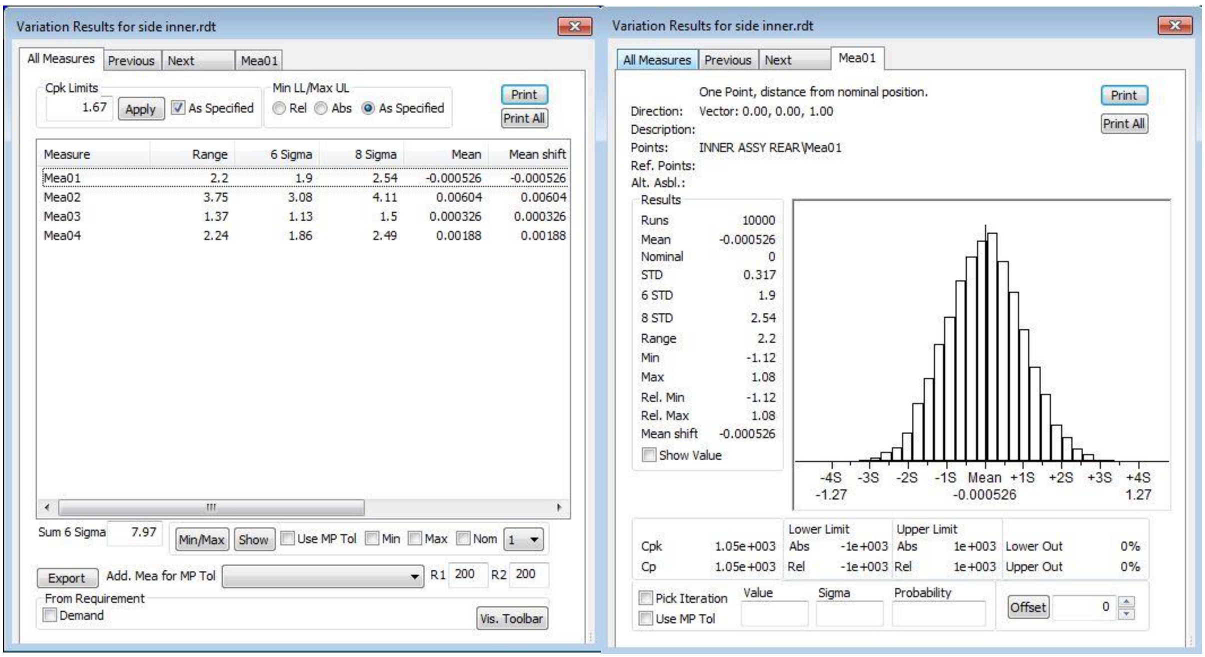
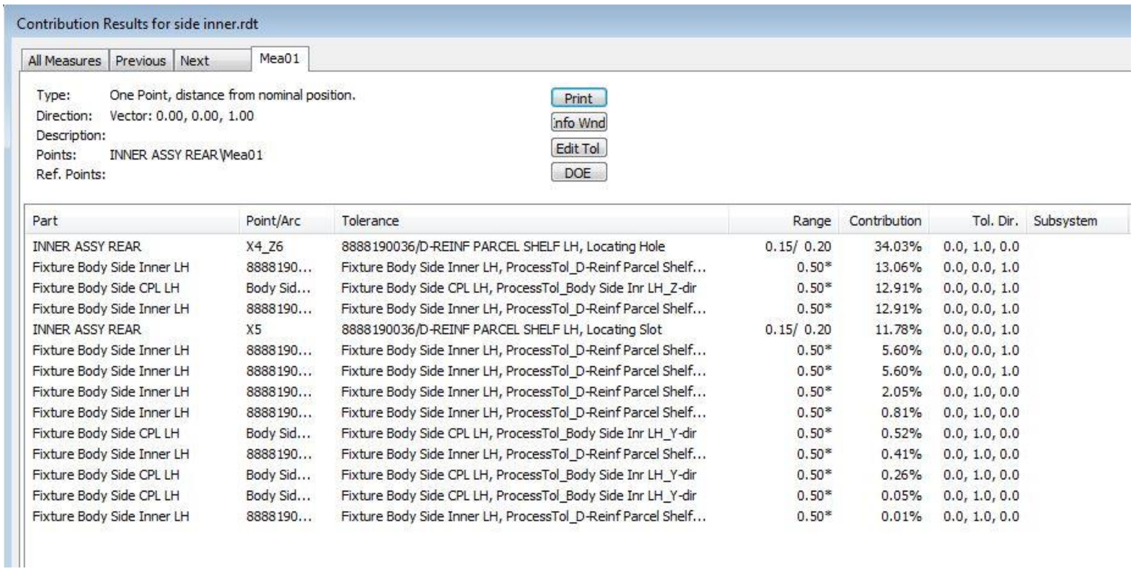


Figure 14: Variation analysis results

4.3.2.3 Contribution analysis

In this contribution analysis, the distributors of each measurement would be calculated and presented with a percentage of the variation influence. This tool can be used to track the unstable causes for each measurement and help users to adjust tolerances or positioning schemes to develop the robust design of the model [4]. An example is given in Figure 15.


Contribution Results for side inner.rdt

All Measures | Previous | Next | Mea01

Type: One Point, distance from nominal position.
Direction: Vector: 0.00, 0.00, 1.00
Description:
Points: INNER ASSY REAR\Mea01
Ref. Points:

Print | Info Wnd | Edit Tol | DOE

Part	Point/Arc	Tolerance	Range	Contribution	Tol. Dir.	Subsystem
INNER ASSY REAR	X4_Z6	8888190036/D-REINF PARCEL SHELF LH, Locating Hole	0.15/ 0.20	34.03%	0.0, 1.0, 0.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	13.06%	0.0, 0.0, 1.0	
Fixture Body Side CPL LH	Body Sid...	Fixture Body Side CPL LH, ProcessTol_Body Side Inr LH_Z-dir	0.50*	12.91%	0.0, 0.0, 1.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	12.91%	0.0, 0.0, 1.0	
INNER ASSY REAR	X5	8888190036/D-REINF PARCEL SHELF LH, Locating Slot	0.15/ 0.20	11.78%	0.0, 0.0, 1.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	5.60%	0.0, 0.0, 1.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	5.60%	0.0, 0.0, 1.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	2.05%	0.0, 1.0, 0.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	0.81%	0.0, 1.0, 0.0	
Fixture Body Side CPL LH	Body Sid...	Fixture Body Side CPL LH, ProcessTol_Body Side Inr LH_Y-dir	0.50*	0.52%	0.0, 1.0, 0.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	0.41%	0.0, 1.0, 0.0	
Fixture Body Side CPL LH	Body Sid...	Fixture Body Side CPL LH, ProcessTol_Body Side Inr LH_Y-dir	0.50*	0.26%	0.0, 1.0, 0.0	
Fixture Body Side CPL LH	Body Sid...	Fixture Body Side CPL LH, ProcessTol_Body Side Inr LH_Y-dir	0.50*	0.05%	0.0, 1.0, 0.0	
Fixture Body Side Inner LH	8888190...	Fixture Body Side Inner LH, ProcessTol_D-Reinf Parcel Shelf...	0.50*	0.01%	0.0, 1.0, 0.0	

Figure 15: Distribution analysis results

4.3.3 Flexset functionality

Since the Flexset functionality is new and still under development, there is no previous work about it. The above presented theory is based on the knowledge acquired by mentoring and by own experiences of authors when using it.

As it was pointed before, Flexset is a new positioning system method. Instead of normal orthogonal and non-orthogonal positioning systems, Flex system could involve several points in just one positioning system while normal system could only have 6. It enables users to test different locating schemes easily both in conducting and visualizing. Users could define several different sets within one positioning system and choose them for specific point easily. The directions could be orthogonal or non-orthogonal according to users' needs. This functionality presents high usability when there are plenty of support points in the model. Different locating schemes can be tested and compared, and the most suitable set can be chosen according to the requirements of users automatically or manually.

A Flexset window displaying different Flex chains is created in the VRML view in this functionality. From this window, users could easily select the specific set from the tree and a triangle for visualizing the locating scheme would be presented in the model. A detailed Flexset functionality instruction could be found in the APPENDIX III.

4.4 Body in White

The Body in White (BIW) is a terminology in automotive industry. The BIW is assembled by several sheet metal parts with different geometries by joining. The most common method in this process is spot-welding. There are around 350 parts in a BIW body joined together. It is used in automotive design and manufacturing before painting [19]. Figure 16 is an example of BIW in automotive industry.

Figure 16: Example of Body in White

5 IMPLEMENTATION AND ANALYSIS

This chapter deals with the implementation and analysis of the previously presented methodology. It covers the identification of customer needs through interviews and observations, analyzing the raw data by using different kind of methods in order to be able to produce a process specification that will help to generate the final concepts and identify the improvement potentials.

5.1 Identifying customer needs

Having a good knowledge of who the customer is and which are the customer needs is essential in order to get a successful start in any project. Putting enough effort and time at the beginning of the project would save plenty of time and probably money at the end. The techniques used to identify the customer's needs in this thesis work are presented in the following sections.

5.1.1 Interviews

The details about how the interviews were implemented are going to be explained in the following sections.

5.1.1.1 Interview strategy

The aim was to interview key persons who could give a description of the current working procedures at their respective departments and the connection and communication processes between them. It was also of interest to find out if some sustainability aspects had been taken into consideration in the development process.

The following departments were considered relevant to the study:

- Manufacturing Engineering (ME)
- Design
- System Engineering
- Dimensional Management

A set of semi-structured interview guides were prepared following a general sequence according to Robson [20] which is presented in Figure 17.

Figure 17: Interview Sequence [20]

The main body of the interview was organized in four areas. The general disposition of the interview guides are listed below:

- Opening questions
- Connecting departments
- Improvement potential

- Capability
- Environmental issues
- Rounding off

For the interview aimed to ME department, some additional sections were added to the main body in other to cover some other aspects within production:

- Current against Flexset and Compliant model
- Quality inspection
- Maintenance

When preparing the interviews, open questions were used with limited amount of Yes/No questions (closed questions) included. This was done in order to get proper explanations on the different topics that could allow the authors to get a better understanding of the subjects. The detailed interview guides can be found in the Appendix A.

5.1.1.2 Carrying out interviews

The interviews were held in a relax atmosphere and without interruptions as suggested by Eklund [21] at CEVT offices and were recorded for later transcription and analysis of the qualitative data. They were from one to one and a half hour long each. As a rule, both authors were present during the interviews. The interviewees were given freedom to answer in their own words and without any time limit.

The sequence of the interview guides was always followed but sometimes some questions were skipped if they were already answered in previous ones or supplementary questions were added when needed according to Ulrich & Eppinger “If a customer mentions something surprising, pursue the lead with follow-up questions. An unexpected line of questions will reveal latent needs” [1].

5.1.2 Observation

Observations and interactions with the customers are a good complement to the interviews to map out the customer needs. The authors were spending over three months at CEVT offices working in this master’s thesis and having the opportunity to observe the working procedures as well as having daily contact with the members of the Dimensional Management department and even other departments. These contacts occurred many times in a very informal way by spontaneous conversations or in form of mentoring sessions. These observations and interactions could reinforce the customer requirements being acquired from the interviews as well as being of huge help in the developing of this project.

5.1.2.1 Visit to Volvo factory

Since there is not actually a production plant of Geely cars and CEVT itself in Sweden, a visit to Volvo cars factory in Gothenburg was carried out. This observation study made in A-factory at VCC gave a brief but helpful view of how the Geely’s body in white assembly plant in Cixi, China should work. Even if A-factory could differ from the actual plant in different matters, the observation was considered useful to get a good understanding of the assembly process of the body in white.

In general, the manufacturing is making-to-order with limited stock of spare parts. The pre-assembly processes and assembly processes of the whole Body-in-White (BIW) of three different models were presented.

The processes start from pre-assembly of floor part, side part and the roof part, and then been assembled together in the final assembly step. There are measurement stations in between after each pre-assembly to do quality inspection and a final laser shop to check the final quality. A manual adjusting station was located after the laser station to finally ensure the quality of the whole BIW. This factory has very high level of automation with robots in every process and only very few workers to ensure the process is working smoothly. Automatic in-house transporting system is used between different workstations with buffers located both in the ground and in the ceiling. Visualization of the information exchange during different stations is realized by the screens in between. The common parts of different models as well as the small parts are outsourced to suppliers and deliver to the factory after produced. Meanwhile, some big parts and parts that are important to the core functionality are produced in-house. The side panel, which is related to this thesis work, is pre-assembled as inner part and outer part separately and then being assembled as a whole, following an assembly sequence that has already been decided in advance. The assembly process uses spot welding to merge contact surface of two parts together. The positions of the fixing points in this process are the detecting areas within this thesis work.

5.1.3 Interpretation of raw data

The next step of the chosen methodology, after gathering the transcriptions from the interviews, was to interpret the collected data. For that purpose two methods have being used. The first one is the costumer data template and the second one is the KJ method. Both methods were explained in chapter 3.2.3 and would be further developed in the following sections.

5.1.3.1 Customer data template

As it was explained in chapter 3.2.3.1, the costumer data template has been adapted to fulfill the needs of this project. The four interviews have been processed together in the same template. In order to distinguish the different departments a color coding was used. Table 1 shows the five categories used in this template as well as the color coding. The whole costumer data template can be found in the Appendix B.

Table 1: Customer data template

Color Coding	System Engineering (SE)	Design	Dimensional Management (DM)	Manufacturing Engineering (ME)
Question/Prompt	Customer statement	Interpreted need	Problem identification	Understanding working procedure

According to Griffin and Hauser [22], the data should be analyzed by multiple analysts in order to identify the largest amount of attributes from the transcripts and avoid preconceived notions. In this case both authors collaborate in elaborating the customer data template as well as in the following steps of the analysis process.

Important customer statements from each interview were copied from the transcriptions and sorted into the different categories of the customer data template. These statements were interpreted in terms of needs, problems and/or understanding working procedure.

5.1.3.2 KJ method

The KJ method has being applied to the processed data from the costumer statements. The method was applied to each category from the customer data template: needs, problems and working procedure. Following the method procedure explained in chapter 3.2.3.2, the labels for each category were produced. The labels that express redundant statements could be stapled and treated as a single label but being very careful to do not omit something important in order to simplify. The main point of this method is to find affinity between the different labels and group them according to a common denominator. Preconceptions about how the authors think it should be, have to be avoided when grouping the labels, it is all about finding the real customer needs, way of working and problems. Each group received a new label that generalized the statements in that group. The analyses were performed in group rooms at CEVT and Chalmers, using the whiteboard, labels and markers in different colors.

5.1.4 Hierarchy and importance of the needs

The following step of the chosen methodology is to give hierarchy to the analyzed qualitative data, in other words to stablish the importance of the needs and factors. In the following section the implementation and analysis of the affinity interrelationship method will be presented.

5.1.4.1 Affinity Interrelationship Method (AIM)

The AIM analysis, which is a further development of the KJ method, was used to continue working with the data. This procedure is based on the manual presented by Sverker Alänge [3] and adapted by the authors to fit the purpose of this master's thesis. The authors proceed directly to the grouping part of the method that had already been started in the KJ method. In the first level grouping all the labels are organized in groups based in the principle of affinity. It is possible to leave individual levels for later grouping. Headings are made in pink post-its for first level groups. A second level grouping is made based on the group's headings and individual labels. It is still ok to leave this "lone-wolfs" alone if they do not naturally belong to a group. New headings in blue post-its are made for this second level grouping. In the third level grouping you continue grouping if necessary and putting common headings in orange post-its. The next step is to find and show connections using arrows just pointing in one direction showing cause-effect, no double arrows are allowed and arrows crossing each other are avoided. The groups are numbered in importance order and circle with markers in different colors. The data has been grouped and organized and the interrelationships are clearly visible. In the evaluation the most important issues are prioritized through group consensus.

After several groupings, the categories can be summarized in seven, five and six groups for customer needs, working procedure and problems respectively. The groups are arranged in hierarchy from one and up. Several rearrangements are considered before taking the final decision and giving them numerical importance. The resolutions in general are of relative character and are based on the authors' experiences with the customers and the observations made during this time. Finally each of the three categories is resumed in one sentence that contains the essence of the analysis.

The figures showed below illustrate the final result of the combined KJ and AIM analysis for each category.

The first AIM analysis showed in Figure 18 is resumed in the following concluding sentence "Customer needs can be summarized by seven groups of requirements as followed". These requirements are going to be presented in detail in chapter 5.2.1.

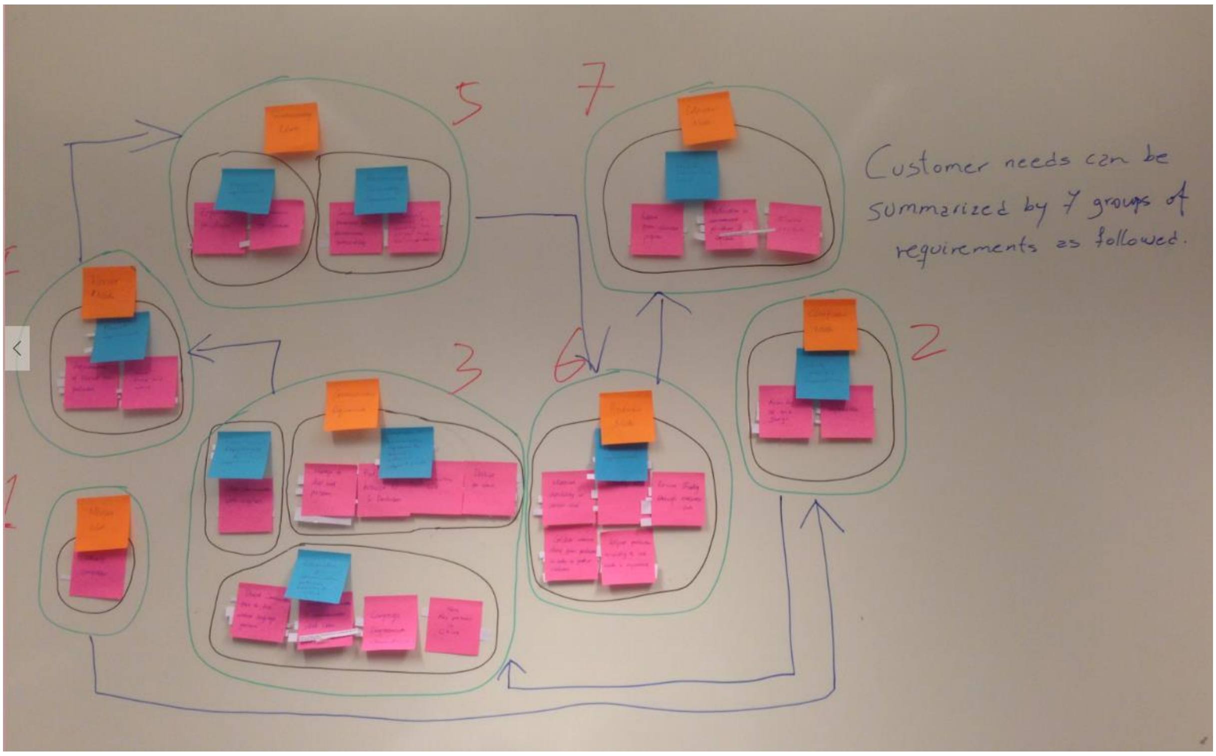


Figure 18: AIM analysis for customer needs

The second AIM analysis showed in Figure 19 has been summarized in the following concluding sentence "The working procedure consists of several actors that interact with each other in other to satisfy quality and sustainability requirements". The results of this analysis are going to be presented in detail in chapter 5.3.3.1.

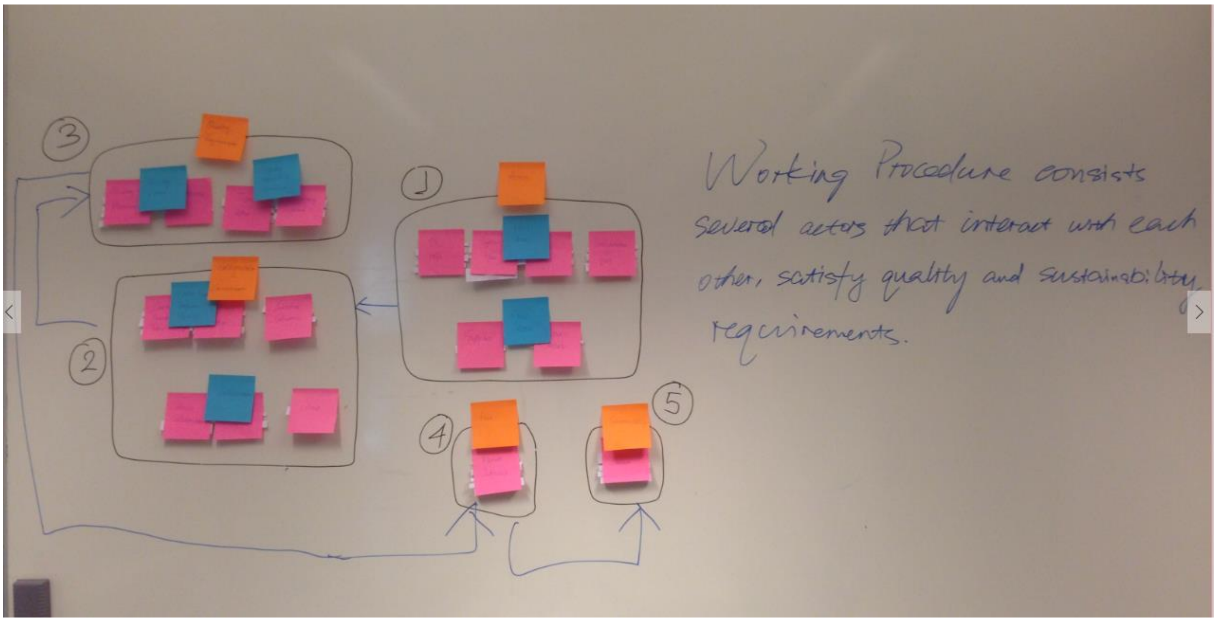


Figure 19: AIM analysis for current working procedure

Finally the last AIM analysis that is showed in Figure 20 reflects the detected problems or in better words improvement potentials in the development process and is summarized in the following concluding sentence “Problems would appear in collaboration and communication, leading to issues in production, quality and sustainability. Each one of the six groups of improvement potentials will be presented in chapter 5.3.4.1.

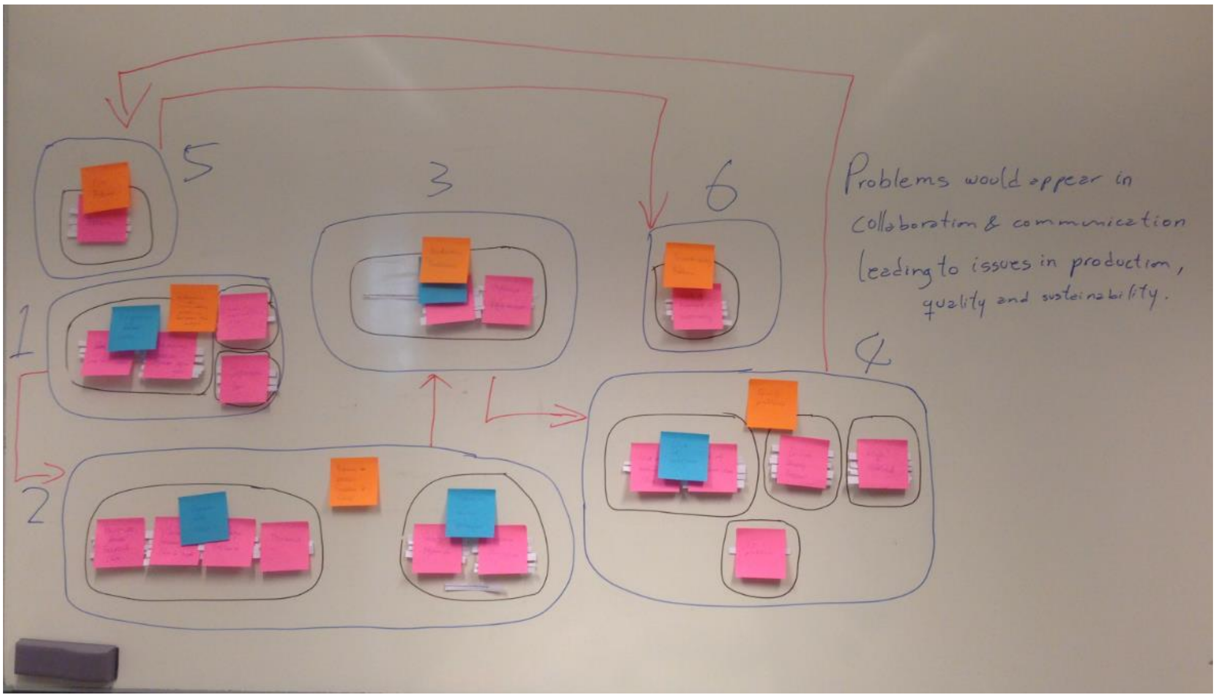


Figure 20: AIM analysis for Problems

From these three AIM analyses it is now possible to continue to the next step of the methodology that is to produce a process specification.

5.2 Process specification

When the collected data has been interpreted, the process specification is been prepared using the results from the previous steps.

The customer needs have to be expressed in terms of process requirements or characteristics in order to be used in the target/process specification. At this point it is mandatory to specify that this method would apply in its totality to a physical product that can be developed and tested. In this case the products are a conceptual current process or working procedure model and a couple of RD&T models. No product concepts are going to be generated and selected by using brain storming, matrixes or other methods usually used when developing a physical product. The working procedure process is going to be presented as it has been understood by the authors, but problems are going to be pointed out as well as future development suggestions.

The RD&T models are produced from existing CAD models, there is no need on generating new concepts since they have already been approved by CEVT. Having clarified this point, the target/process specification will be adapted for fitting this work.

5.2.1 Customer needs

The customer needs have been identified during the analyses explained in chapter 5.1. They can be resumed in seven fields that are going to be presented in this section. Not being able to accomplish the customer needs in their totality has led to the problems that have been identified and will be presented in chapter 5.3.4.1. Hopefully these analyses would help to clarify the current weaknesses during the product development process and to suggest possible solutions to improve the working procedure.

1. Market need – It is imperative to have a clear vision on how the market looks like and to identify the competitors.

2. Clarification needs – A necessity to clarify roles and responsibilities in order to avoid misunderstandings have being expressed, especially by System Engineering and Design departments.

3. Collaboration and communication requirements – Can be divided in three aspects:
    - Communication requirements for suppliers
        - A necessity to have a clear communication with suppliers to avoid misunderstandings.
        - It is necessary to have a window person with good technical and language skills when communicating with suppliers.
    - Collaboration and communication requirements between different departments
        - Have meetings to deal with problems.
        - Avoid information loss is necessary.
        - Find balance between product development and production.
        - Deliver on time is mandatory.
    - Collaboration and communication requirements between Sweden and China

        - Face to face communication is necessary.
        - Better collaboration and communication with China to avoid unnecessary expenses and misunderstandings.
        - Language improvement both in Chinese and English for better communication is necessary.
        - To have key persons in China who can supervise the work and can inform back to Sweden.

4. Flexset needs – To serve the purposes of this master's thesis the authors have been able to identify some customer needs regarding the use of the new Flexset functionality, these are like follows.
    - Flexset should not interfere with other important requirements.
    - Requirements of Flexset from production:
        - Simple and clear
        - Easy to analyze
        - Better calculations and more realistic results are desirable.
    - It should save time and money in the evaluation phase.

5. Sustainability needs – Can be divided in environmental and social sustainability needs, the last one expressed in form of ergonomic requirements.
    - Environmental sustainability requirements
        - Smart material choices for keeping low weight and fuel consumption.
        - Necessity to increase awareness in environmental sustainability to diminished the impact on the environment.
    - Ergonomic requirements
        - Good ergonomic for workers at the factory is desirable.
        - Good ergonomic for drivers is a priority.

6. Production needs – have been expressed as follows.
    - Collect measure data from production in order to predict variation. Since the first project has not been released yet, there is no measure data from production available yet, and measure data from Volvo is been used as well as the engineers' knowledge and experience.
    - Adjust production according to real needs and experiences.
    - Measure capability in certain time.
    - Identify KPIs.
    - Ensure quality through measurements.

7. Education needs – have been expressed in the following terms.
    - Need to educate and learn about communication, common working procedures, software and environmental issues.
    - Learn from current projects in order to improve methods, processes and timing for future projects.
    - Improve IT-tools.

5.2.2 Process/target specification

Table 2 shows the Process/target specification that is going to be used when creating the conceptual working procedure model for product development of body in white used at CEVT. It is based on the customer needs that have been presented in the previous section. Each need has been given an importance weighting in a scale from 1 to 5 according to the authors understanding of the customer needs. It is clear that the most important needs regards clarification, communication and collaboration between the different actors as well as learning from the current projects in order to improve and eventually adopt a common working procedure. The Flexset needs are going to be taken into consideration when testing the RD&T models.

Table 2: Process/target specification for customer needs

No.	Need	Imp
1	Market need: Identify competitor	4
2	Clarification needs: Clarify roles and responsibilities	5
3	Communication requirements for suppliers	5
4	Collaboration and communication requirements between different departments	5
5	Collaboration and communication requirements between Sweden and China	5
6	Flexset needs: Not interference with other important requirements	4
7	Requirements of Flexset from production: simple and clear, easy to analyze, better calculation and more realistic results.	4
8	Environmental sustainability requirements	4
9	Ergonomic requirements	4
10	Collect measure data from production in order to predict variation	3
11	Adjust production according to real needs and experiences	5
12	Measure capability in certain time, identify KPIs	4
13	Learn from current projects	5
14	Education in communication, procedures and software	4
15	Improve IT-tools	3

5.3 Concept generation

In this sub chapter, the concept generation part of the methodology will be presented starting with the work case, through the different models in RD&T and the generation of the working procedure model of the product development process using the collected and analyzed data presented in the previous sections. Even the improvement potentials detected during the concept generation will be treated.

5.3.1 Work case

The body side panel both inner and outer of the body in white for a specific Geely car model has been implemented as the chosen work case. Due to the confidentiality of this project the authors are not allowed to reveal the name of the car model.

The chosen model contains eleven parts in four sub-assemblies and four different levels. The following Figure 21 shows the structure of the chosen case.

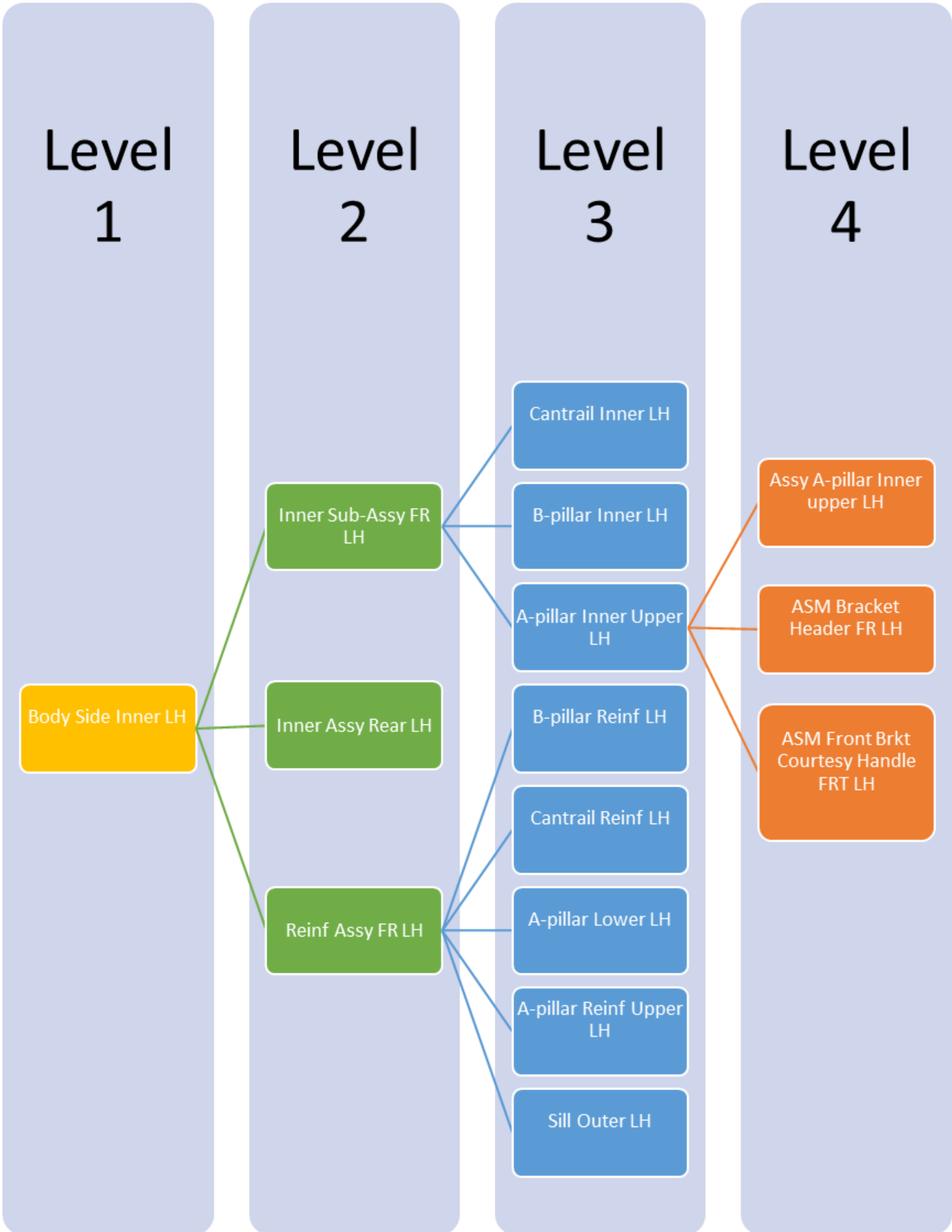


Figure 21: Chosen case

The model was built following the assembly sequence that can be found in the given documentations in Teamcenter, which is a PLM software used at CEVT. The original CAD files are also acquired from Teamcenter and imported into RD&T after file transformation made by the authors.

5.3.2 Modelling in RD&T

As it was explained in chapter 3.4.2, modelling in RD&T allows the user to choose between different ways of modelling in the same program. The ones used in this master's thesis are presented in sections 5.3.2.1, 5.3.2.2 and 5.3.2.3.

5.3.2.1 Modelling with six directions positioning system

In this thesis work, a model with six directions positioning system was already created by engineers in the Dimensional Management department in CEVT. This given model was reached by the sharing documentation within this department. Authors in this thesis spent two weeks going through the whole side panel model and got familiar with this real case. The tolerances, measurements as well as all the locating points were studied combined with work standards in CEVT. The two authors used this model as a startup for the following modelling in Flexset functionality as well as a step to understanding the current working procedure within this department.

5.3.2.2 Modelling in Flexset functionality

During this thesis, a new model only with the new testing Flex functionality was created by the work of authors. A brief working procedure is explained in the Figure 22.

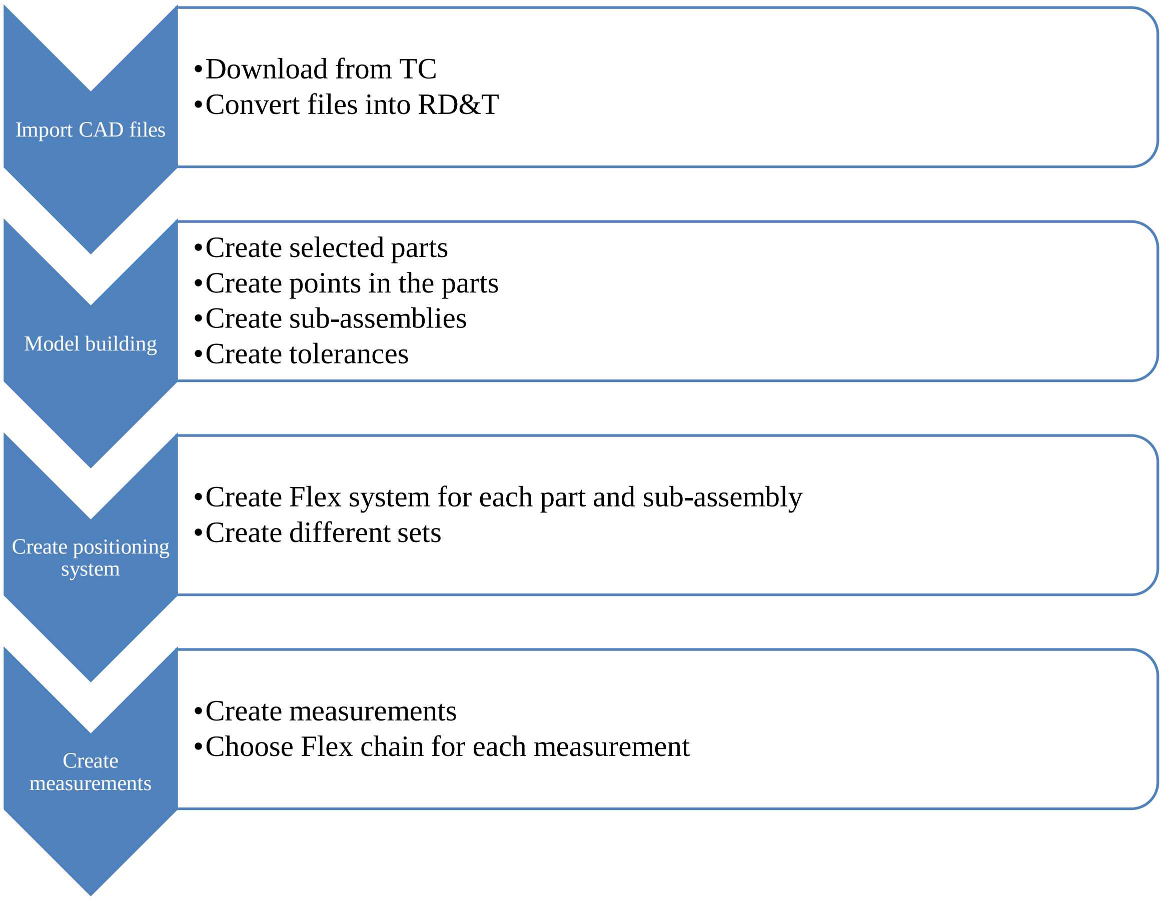


Figure 22: Work process of Flexset modelling

The original CAD files were reached from Teamcenter (TC), which is a PLM (Product Lifecycle Management) software and is used in CEVT for users to import or export needed documentation and information; and then converted into RD&T. Considering the time limits in this master's thesis, only 11 parts has been selected and are going to be tested in this new functionality, some small parts were merged together in order to save work. To use Flex functionality, all the six main points as well as all the support points were created in each part according to the PMI files (3D drawing digital files in Teamcenter that indicates all the information such as tolerancing and mating surface etc.) from TC. There are four sub-assembly levels and four sub-assemblies in this model, which was shown in Figure 21. This structure was conducted according to the POPS of this car model, the welding sequence guidance within CEVT.

The locating positions on the part levels were selected based on the 3D PMIs that were shown in the models from TC. Also the PKRV files within CEVT were used as guidance of finding the locating positions of all the sub-assembly levels. From these documentations, all the main points, as well as the support points, could be found as locating points used in Flex positioning system. The sub-assembly structure in the VRML window within RD&T is displayed in the Figure 23.

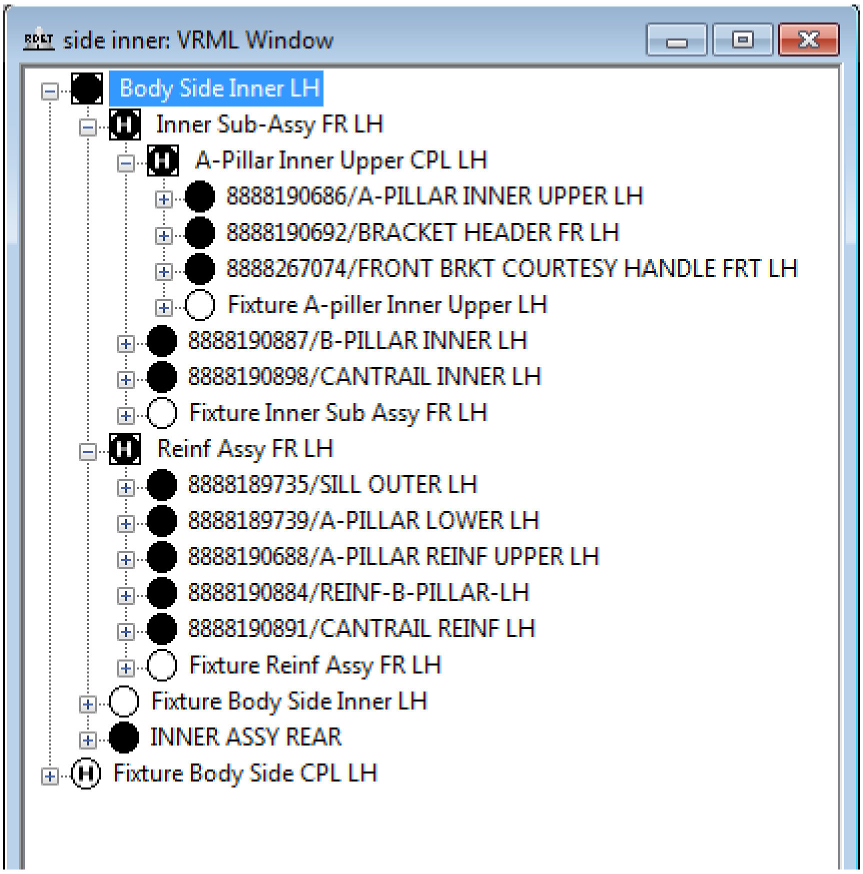


Figure 23: Sub-assembly structure in RD&T

To ensure the whole model would act as close as in the reality, tolerances were given according to the information getting from the internal documentations about the standards within CEVT and also the oral guidance from mentors in the Dimensional Management department at CEVT. There are three different tolerances given in this model: the mating surface tolerances, the process tolerances and the locating holes/slots tolerances. The mating surface tolerances were decided according to the Volvo Car Standard VCS 5023.8. Tolerances of the locating holes and slots were also decided according to the VCS 5023.8 as well as the International Standard ISO 2768-1. The last kind of tolerance, process tolerance, was given by Henrik Persson, the senior dimensional engineer of Dimensional Management department. The process tolerances are uniform distribution in this project, while the other two kinds of tolerances are normal distribution.

As stated before, this model was only built with the new Flexset functionality, which means only Flex positioning systems in each part and each sub-assembly were created with all the points that had been defined before. After creating all the points both in the local parts and target parts, different sets were created according to the requirements of further comparison in measuring points. Since there was no documented work found in this functionality, this work was done by authors' self-exploring and guidance from other dimensional engineers in CEVT. A detailed instruction about how to use this new Flexset functionality within CEVT and the explanation of this new functionality could be found in the Appendix III and it also works for different situations that need to use this new functionality. It was formulated according to the requirements of CEVT and PE Geometry and conducted by the authors. The directions of the positioning system in this model were only orthogonal directions in order to simplify the tasks.

To compare the two positioning methods, four measuring points were created with measurements in the model. According to the calculation behind this Flex function, the default set in each Flex system would only use the six main points into calculation. Theoretically, alternative assemblies would come with exactly the same result as in Flex if using the same locating points on the measurements. So the comparison would be the usability of these two methods experienced by the authors. The measuring data should theoretically be the same in these two models.

In the testing, a function in Flexset called ¨Find Suitable¨ is tested in order to make the selection of a different set to come automatically with the most realistic choice, as it can be seen in Figure 24. Since Flexset functionality is very new and there is no previous work on it, some problems have been found during testing and will be explained in the Chapter 5.3.4.2.

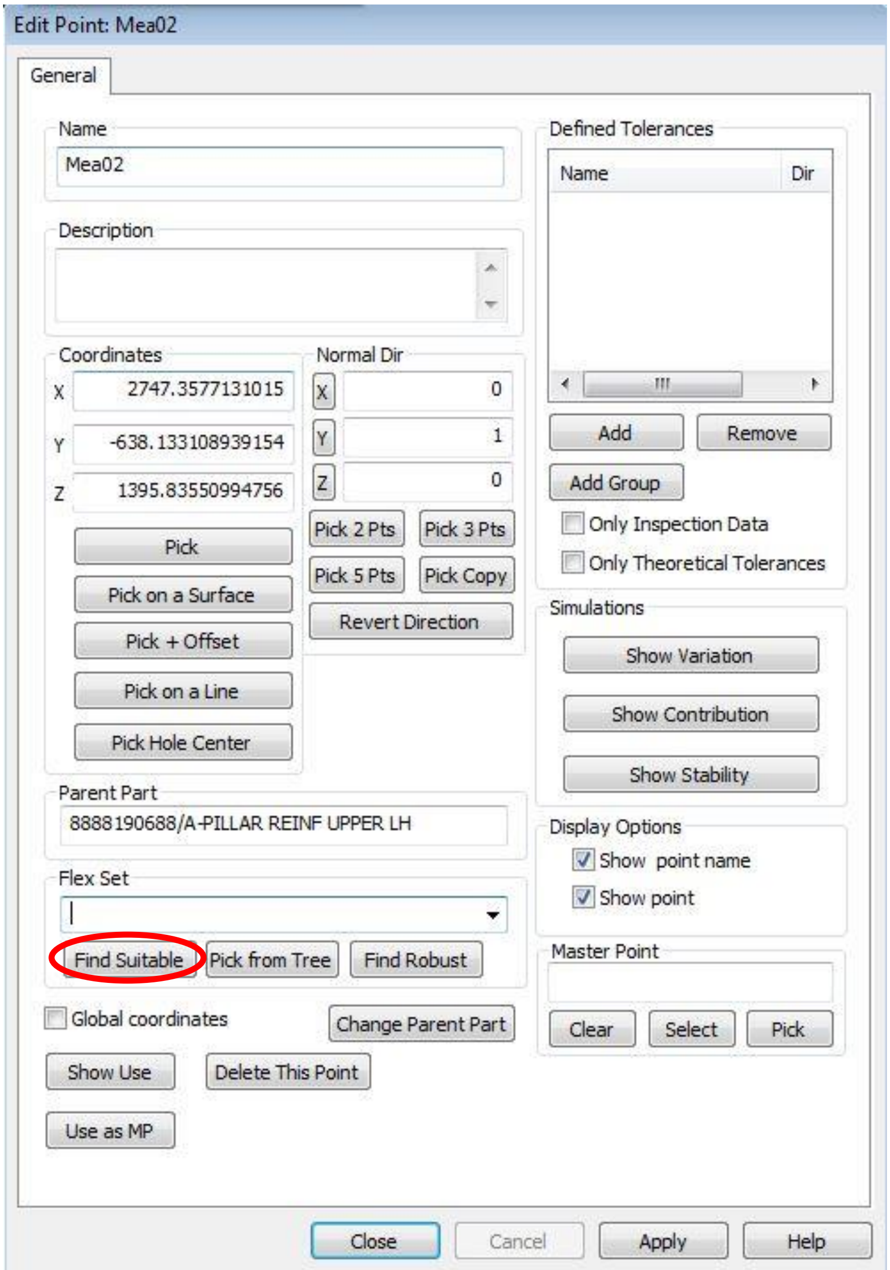


Figure 24: Find Suitable in Flex

5.3.2.3 Modelling in alternative assemblies

Since Flexset functionality is aimed at using different locating schemes in order to compare and find the most realistic one, the alternative assembly, which has the most similar features need to be compared. Another model was created without any Flex positioning system, but only with the 6-directions positioning system. In order to compare the usability of these two functionalities, the alternative assemblies were created using exactly the same locating schemes as the ¨Find Suitable¨ suggestions in Flexset. The list of created alternative assemblies and one example of the positioning systems in Measurement 1 are shown in Figure 25 and Figure 26 respectively.

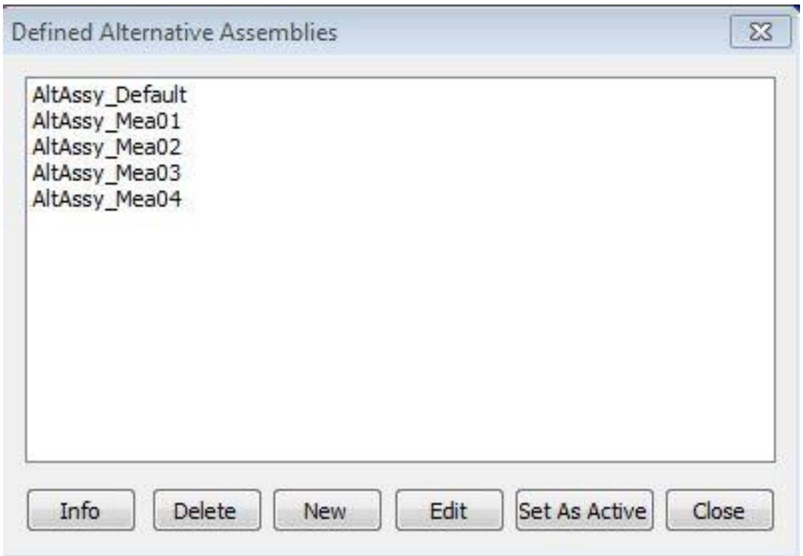


Figure 25: List of created alternative assemblies

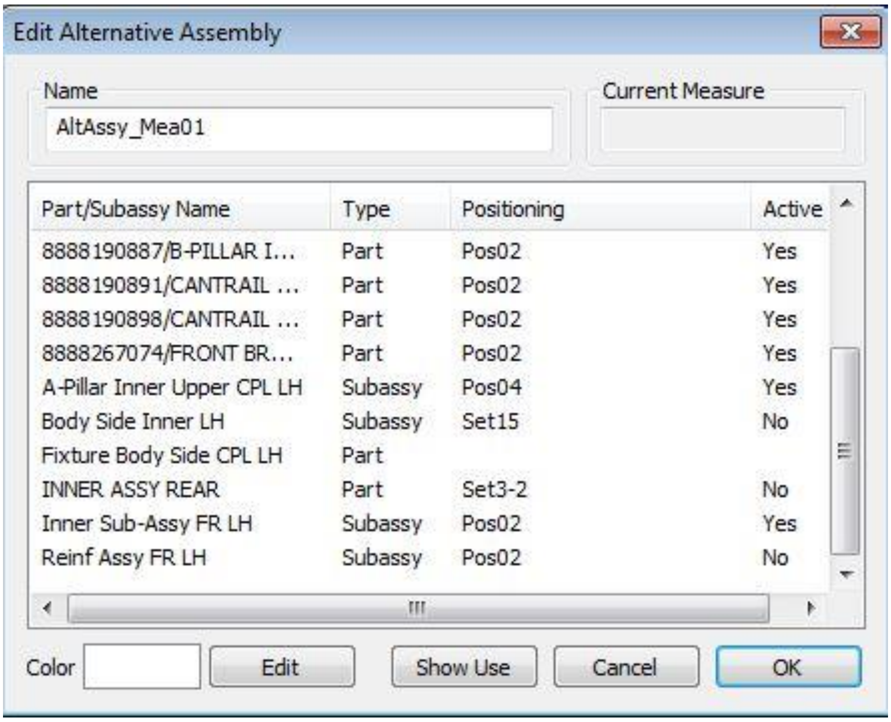


Figure 26: Positioning systems in Measurement 1

To ensure the comparability of these two models, this model was created based on the copy file of the Flex model. All the tolerances and defined points, as well as positions of measurements were exactly the same as in the Flex model in order to be compared. The only changes that the authors made, were deleting all the Flex positioning systems and creating 6-directions positioning system for all the parts and sub-assemblies, using the exactly same points as used in Flex model. Also the suggested locating sets in Flex model were created. This thesis aims to test the Flex functionality and compare the usability between Flex and alternative assemblies. According to the same calculation processes behind these two functionalities, the simulation results of variation simulation should be the same in the two models theoretically. This comparison would be explained in Chapter 6.2.

5.3.3 Working procedure

From the processed data obtained from the KJ and AIM analysis, a set of factors have being identified, that have helped the authors to understand and create a model that reflects the current working procedure used during the product development process of body in white at CEVT. These factors will be presented in the following section.

5.3.3.1 Identified factors

The identified factors can be divided in five groups that will be presented below.

1. Actors: The involved players in the working procedure process can be divided as follow.
    - Main actors: The most important players are the following departments at CEVT.
        - **Dimensional Management (DM)**: consists on DE (dimensional engineering) and PQ (perceived quality).
        - **Manufacturing Engineering (ME)**: GEO ME is the interesting actor in this process.
        - **System Engineering (SE)**: They are considered to be the spider in the net.
        - **Design**: consists on Styling and Studio Engineers.
    - Other actors: Here are considered other players that also take part in the working procedure, who are important and cannot be neglected.
        - Input actors: Attributes, packaging department, safety and legal requirements.
        - Suppliers
        - CEVT Hangzhou – China: The Chinese office in Hangzhou is considered to be an indirect actor and is also called the back office.
        - Production Cixi – China: The body in white will be produced in the factory in Cixi.

2. Collaboration and communication
    - Cross-functional team meetings between the main actors to generate solutions and solve disagreements are taking place. If no agreement can be made, SE is responsible for the final decision. Integration meetings between design, SE and packaging department occur on a weekly basis to arise issues regarding styling. Internal meeting within the departments are conducted.

- Collaboration
  - Vertical collaboration: meetings with leaders every quarter of year, half a year and annual review.
  - Release: 5 loops before the final release of the body in white.
  - Collaboration with China: Sweden is the front office and handles work to China, like RD&T calculations. China needs approval from Sweden.

3. Quality requirements
   - Defining references and tolerances
     - Incorporating experiences: Deciding reference systems and tolerances relays on the engineers' experience.
     - Tolerance definition: Start from standard tolerances, Volvo's measure data is being used. DM sets up the tolerance level. A consensus between DM, ME and SE is used to set the final tolerances. These tolerances may affect styling by Design is not involved in deciding tolerances; tolerance data input is given by SE to Design.
   - Quality control
     - Quality check and measurements: Samples shall be taken 3-5 times per week. It takes 5 weeks to get measuring data. Measuring machine and manual measurements will be made.
     - Maintenance: Time-based preventive maintenance will be applied.

4. Flexset influence
   - Better predictions are expected or at least as accurate as those made using alternative assemblies.
   - Good complement: Adopting Flexset would not affect the daily work of SE and could be used as good complement.
   - No effect in production should be noticed. Saving time and money in the launching phase is desirable.

5. Sustainability
   - Ergonomic for drivers and workers at the factory: Ergonomic department lies under vehicle integration (need confirmation). ME takes care of ergonomic aspects at the factory in China.
   - Company policy regarding environmental issues exists but the authors could not find it.

These five groups resume the factors that have been identified through the analysis of the collected data and are along with the process/target specification the basis for creating the working procedure model.

5.3.3.2 Generating a working procedure model for product development at CEVT

The next step is to generate a conceptual working procedure model for product development of body in white based on the identified factors that interact in this process and the customer needs reflected in the process/target specification. The model aims to show a realistic view of the current way of working with both the pros and cons. The results of this work will be presented in chapter 6.1.2.

5.3.4 Identifying improvement potentials

Improvement potentials in the product development working procedure have being identified from the processed data explained in earlier sections and are going to be presented in this subchapter. Another set of improvement potentials regarding the use of Flexset functionality in RD&T has also being identified and will be presented as well.

5.3.4.1 Identified problems in the product development process

It is important to emphasize that CEVT is a quite new company in Sweden and they are doing their best to accomplish their goals, and it is far too soon to see the results of their efforts since no project has being released yet, but during this time the authors have been able to identify some problems in the working procedure process that are important to point out in order to improve this one and find possible solutions.

In this section the problems that have being mapped out from the KJ and AIM analysis are going to be presented in relative importance order. These problems can be summarized in six groups that would be explained below.

1. Collaboration and communication problems between the actors. The actors have being presented before, see chapter 5.3.3.1.
    - Clarifying responsibilities: Sometimes there is a lack of awareness about who bears the final responsibility when collaborating with China, one of the interviewees referred to a possible language issue or being in the process of learning from current projects. See Appendix II Customer data Template.
    - Information loss: Bad communication between the departments can lead to information loss; all important changes must be informed. Information losses can even occur when people are changing departments or leaving the company. Another problem is the big flow of irrelevant information that can lead to important information being lost in the flow.
    - Disagreements between actors: A detected problem is that disagreements with suppliers can occur and can generate extra loops. It has happened that suppliers have start working without approval generating unnecessary costs. Disagreements even take place internally between the departments in CEVT, different opinions, geometry assurance disagreements between SE, DM and ME or different perspectives between stylists and system engineers. These are usually solved through meetings.
2. Problems between Sweden and China
    - Differences in structures and philosophies: People come from different backgrounds and places and work in different ways. Since the company is still young, there is not a common way to do things. There is a tendency to do things the way it has always been done, a resistance to change or adapt. There is also a cultural difference in organization structure, the Chinese hierarchical organization structure against the Swedish more flat structure, can cause misunderstandings. Sometimes decisions are made from above due to the distance that difficult to have time to listen to details, and having face to face communication.

- Problems with China
    - Misconception between Sweden and China: Working in different ways and lack of information leads China sometimes to take wrong decisions without approval. Even the desire from China to implement changes as soon as possible can lead to expensive consequences, for example start working with a supplier before approval.
    - Communication problems between Sweden and China: Miscommunication between Sweden and China regarding delays at the factory has led to waste of money in unnecessary trips to China. One of the interviewees recorded a time when a stylist was send to China to check on a part that has not being produce yet and nobody have being informed about it. The stylist had to return to Sweden and reprogram the trip for later.
        - Language: Difficulties in communication due to different languages and level of language skills, both in Chinese and English. The corporate language is English, and sometimes the level of proficiency is not good enough. Difficulties in untangling the corporal expressions may appear. Translators not having good technical knowledge are a problem.
        - IT tools: IT tools for communication with China do not work as good as they should. The Chinese are still learning the software and need confirmation on their work.
        - Distance difficult communication face to face. Long trips are required. Long distances make solving problems in time more difficult to achieve. The difference in time zones also difficult the communication between Sweden and China since China is seven hours ahead.

3. Production problems
    - Different requirements from the actors: Different departments have different requirements on the product and each one wants to prioritize its own requirements. Sometimes disturbances from other requirements can occur in production.
    - Different needs in real production: Everything that is done in production gives variation that is not reflected in the simulation. Realistic variation differs every time. Matching is not as perfect as in Catia.
    - Factors not considered: A lot of process parameters are not included in the simulation like manual work, gravity etc. Not consider process impacts either. New processes in production will bring new problems as well.

4. Quality problems
    - Lack of real measure data from the plant in China: Since the first project has not being released yet, there is no measure data available for setting the tolerance level and predict variation. Currently measure data from Volvo is being used as well as the engineers own experiences.
    - IT problems: RD&T cannot be opened directly from Teamcenter. Communication between different software should be easier.
    - High workload: Not enough capacity when engineers are working in at least two projects simultaneously. High workloads lead to difficulties in communication and meeting face to face. Lack of experience in common working procedures in some departments can result in delay of deliveries,

which derives in increasing the time pressure and workload in other departments.
    - On-time delivery problem: "The time plan is never on time", is a quote from one of the interviewees. It has been difficulties following the time plan and catching up the milestones. Delay in one area causes delays in other areas. In the long term can cause the project becoming more expensive. Rushing around to deliver on time can affect the quality of the parts.

5. Flex problems
    - Preconceptions: It seems to be preconceptions about Flexset being more difficult to use than alternative assemblies or giving strange effects. Engineers' concern about using too many support points has been expressed. It seems not to be clear how it should be measured and verified in Flexset.
    - Resistance to change: There is a risk that the engineers choose not to use Flexset and continue using the RD&T tool in the same way they do today. People have a tendency to continue doing things the same way they have always done.

6. Sustainability problems
   There is a lack of awareness in environmental sustainability matters and very little awareness about social sustainability. It seems not to be clear who is responsible or which department is in charge of these areas. The authors have not being able to make contact for an interview with anyone regarding these matters and were unable to locate the company's environmental policy. Producing environmental friendly vehicles is clearly still not a priority.
   In general there is an unbalanced development between Sweden and China concerning sustainability issues.

5.3.4.2 RD&T: Flexset

Here are some detected developing potentials within Flexset functionality in RD&T software according to the authors' experience from the user perspective.

Flex general

1. When editing each set, the user needs to go into the positioning system and define it. It would be more useful if it could be edited directly by double-clicking on the name of it or choosing from the right click menu.
2. It should be easier when user want to change flex set in higher levels manually. Now it can only be changed by going into the positioning system in each level. It could be the same solution as first suggestion.
3. It is desirable that the triangle of the default set could be displayed in the window.
4. Every time the edit point is clicked on, the whole point list of this part would be expanded in the flex window in VRML view. It is disturbing with too many points there and perhaps it would be better if only the part that this point is located on would be highlighted without expansion.

As stated in the beginning of this chapter, these perspectives are the identified improving areas in the usability perspective from the own experience of authors. During the master's thesis period, the authors have discussed these suggestions with Lars Lindkvist, the developer of the RD&T and Flexset function. The third point has already been incorporated in the new version of RD&T. The verification result of the Flex functionality would be analyzed in the Chapter 6.2.

5.3.4.3 Sustainability

The problematic around the lack of sustainability awareness has already been briefly presented in chapter 5.3.4.1. Here the authors feel the responsibility to emphasize the importance of implementing a conscious environmental policy in CEVT that is known and applied by all the employees. Since the authors could not read the existing one and this seems to be unknown to the engineers, it is not possible to give a full recommendation about which areas need to be improved, but in general and in accordance with the global concern in sustainability matters, there is a lot to be done in order to contribute to diminish the impact on the environment as well as to improve the physical and mental condition of the workers at the factory. More concrete suggestions will be given in chapter 7.4.4.

6 RESULTS

The results of this master's thesis are going to be reported in the following chapter under the headings concept selection and concept testing. The working procedure model will finally be presented and the RD&T models will be tested in terms of usability or user-friendly perspective.

6.1 Concept selection

At this point of the master's thesis the authors have acquired and processed information enough to finally allow presenting a model for the current working procedure for product development of body in white at CEVT. The model is going to be presented in the following section.

6.1.1 Working procedure model for product development at CEVT

Based on the identified factors presented in Chapter 5.3.3.1 and the process/target specification, as well as the author's observations during this journal, a conceptual model of the current working procedure for the product development process of the body in white at CEVT has been generated. The model is shown in Figure 27.

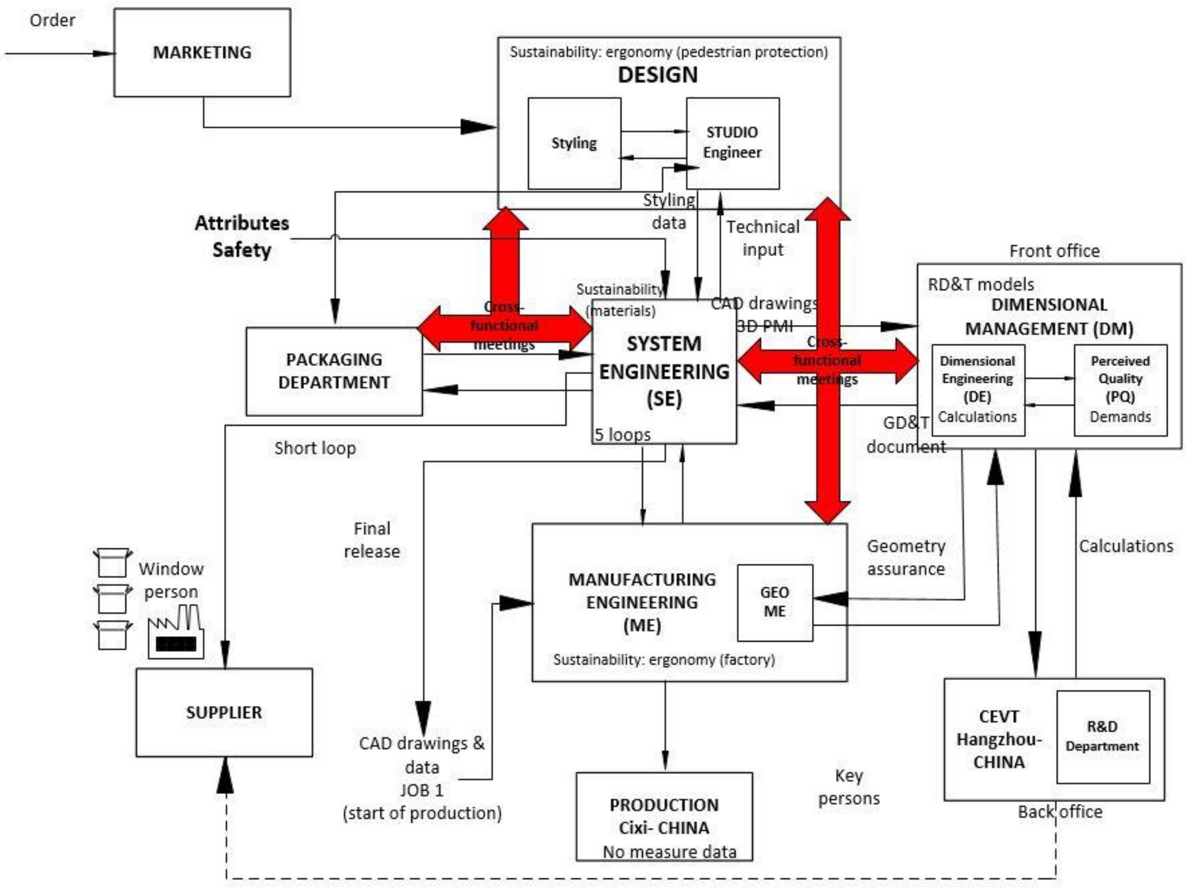


Figure 27: Conceptual model of the current working procedure for product development of body in white at CEVT

The working procedure model presented above reflects the current situation at CEVT during spring 2016, in the way the authors have interpreted the collected data. The model tries to reflect as real as possible the process that involves the main and other actors and their interrelationships, the different inputs and outputs, but even tries to incorporate their relationships with other not investigated players like the production factory and the back office in China.

As can be seen in Figure 27, in the middle of the model it is placed the System Engineering department that acts like a kind of spider in the net who handles the contacts with the other departments in form of cross-functional meetings that are represented by the red crossing arrows in the model. The process starts with an order placed by Marketing and coming into the Design department. Inside the Design department, there are stylists and studio engineers, the last ones act like an interface in between stylist and engineers and manage all contacts and meetings with both system integration and packaging department and System Engineering. Several phases of interchange of styling data and technical input happens between Design and System Engineering until the first CAD drawings can be released from System Engineering to Dimensional Management.

During this process several cross-functional meetings between Design, Packaging and System Engineering are taking place to deal with styling issues as well as internal meetings within the departments. Other factors as attributes, safety and legal requirements are coming as input to System Engineering that has to be taken into consideration. The Catia 3D PMI drawings are released and Dimensional Management can start producing the RD&T models based on those drawings. There is collaboration with the Manufacturing Engineering department, especially with GEO ME to agree in tolerances, reference points and other requirements regarding the geometry assurance field.

Inside Dimensional Management there are two groups: Perceived Quality (PQ) and Dimensional Engineering (DE). PQ sets up the final demands on the car and DE calculates if it is possible to fulfill these demands. Internal meetings between PQ and SE are carried out weekly. In these meetings the Chinese are participating via Skype. Dimensional Management collaborates with the R&D department at CEVT China located in Hangzhou. CEVT Sweden is considered to be the front office; meanwhile the office in China can be called the back office. Dimensional Management hands over work like calculations to do to the office in Hangzhou and they have to report back to Sweden, they cannot take decisions without approval from Sweden.

Besides the internal meetings, cross-functional meetings between Design, System Engineering, Dimensional Management and Manufacturing Engineering are taking place in special times during the project.

Finally the GD&T documents are released from Dimensional Management to System Engineering who handles all contact with suppliers, sometimes there is a short loop between System Engineering and the supplier when the supplier have some suggestions, but this is usually quickly solved by the supplier changing the first set up to what Dimensional Management actually proposed. Here it is important to have a so called window person with not only good language skills but also with good technical skills to serve as a translator between the engineers and the supplier.

The process of System Engineering releasing the final Cad drawings and data takes five loops, when reaching the last official one, the drawings are released to pre-production and several loops are happening until moving from the pilot plant to the actual factory. System Engineering is responsible until three months after the start of production or JOB1. After that time the responsibility goes to Manufacturing Engineering. The production will take place in the factory located in Cixi – China. So called key persons from Sweden are important to place in China in order to supervise, educate and report back to Sweden.

The model shows a dashed line that goes from the back office in Hangzhou to the supplier. It represents an unauthorized started order that has actually happened but that should not be there.

Because of the time factor the authors have not tested the presented conceptual working procedure model.

6.2 Concept testing

The following subchapter will cover the testing of the RD&T models. As demonstrated in the Chapter 5.3.2, the expected variation simulation results in the Flex model and the alternative assembly model should be exactly the same. Then the comparison would only cover the usability in these two ways of modelling that has been experienced by the authors. The authors have built these two models strictly following the documentations that gave guidance on locating schemes from CEVT, such as POPS and 3D PMI from TC, as well as the current complete car model created by CEVT in RD&T for this project as a reference. These two models are robust and valid for evaluation and comparison.

During model establishing, there were some problems occurred with the Flex model based on the calculation behind. This model was expected to achieve the same variation analysis result by calculation as in the 6-directions positioning system with the same locating scheme for each measurement. Theoretically, the calculation process should be the same and this result should be able to be achieved. In the reality, there are some unknown problems behind the calculation, which result in unrealistic variation simulation result in Flex model as in Figure 28. They are variation simulation results from Flex model in the left side and from AA model in the right. It is obvious that the results are highly different in all the measurements.

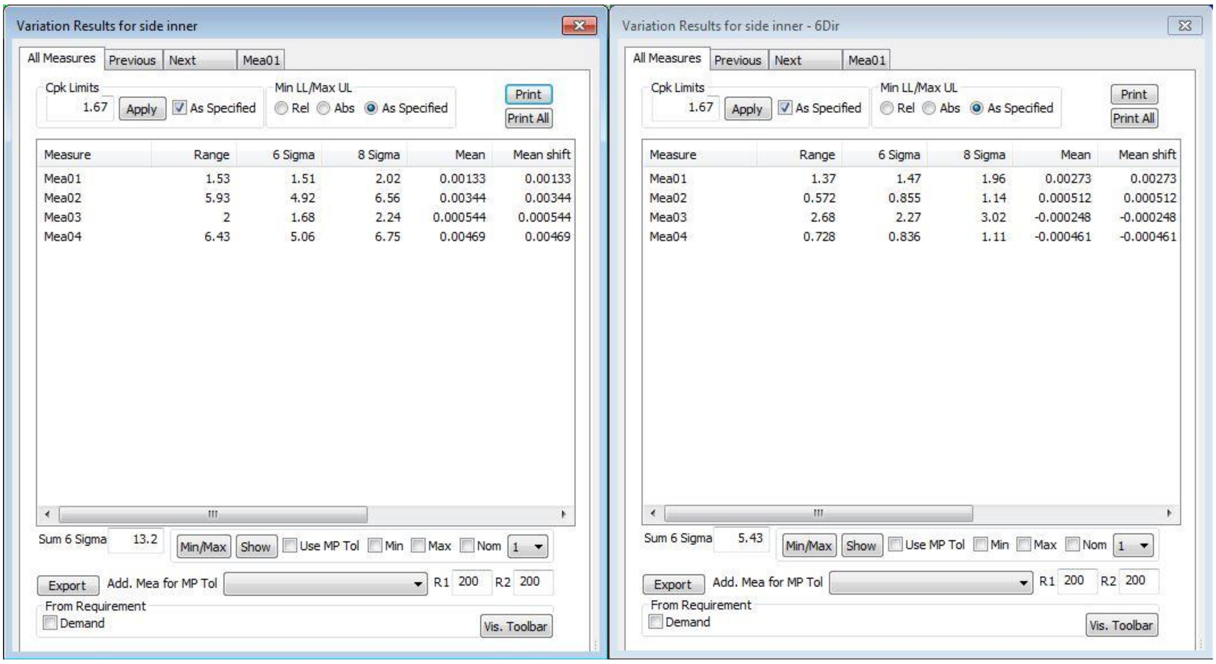


Figure 28: Variation simulation results in two models

Basically, the Flex functionality was expected to achieve the most realistic result compared to the alternative assemblies on the 6-directions positioning system. This means that the ¨Find Suitable¨ function in Flex could suggest the most realistic locating schemes from part level to each higher sub-assembly levels that have been defined by the users. This ¨Find Suitable¨ function works as expected in the Flex model, suggested a whole Flex chain with a specific Flex set in each level. The problem is that, the local points in sub-assembly levels could not be the local points on the part level, which resulted in the wrong calculation of variation analysis results. This possible reason has been tested by the authors in Mea01.

This Mea01 was used as a test of the possible problem and the result had verified this guess. This measurement only has two assembly levels, the part level and one sub-assembly level, which make the test possible and easy to make changes. This problem would bring more conflicts in other measurements with three or four assembly levels. Also it is extremely complicated to analyze so many assembly levels to get around this problem in order to compare. Due to these reasons, other measurement results would not be compared in these two models.

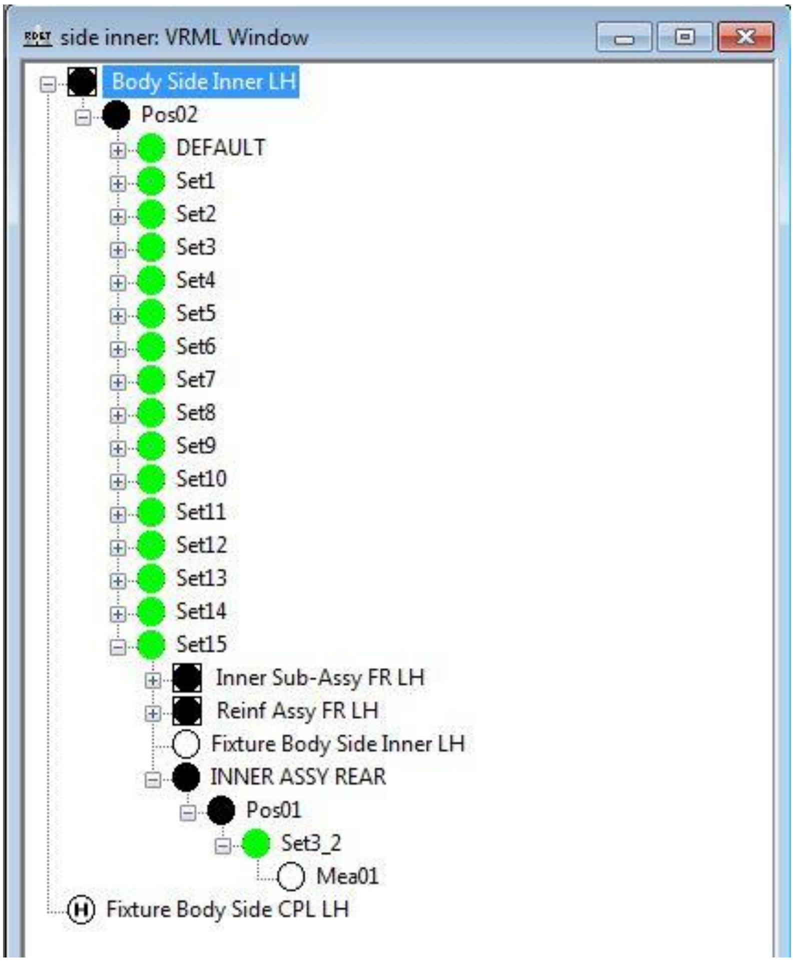


Figure 29: Suggested Flex chain in Mea01

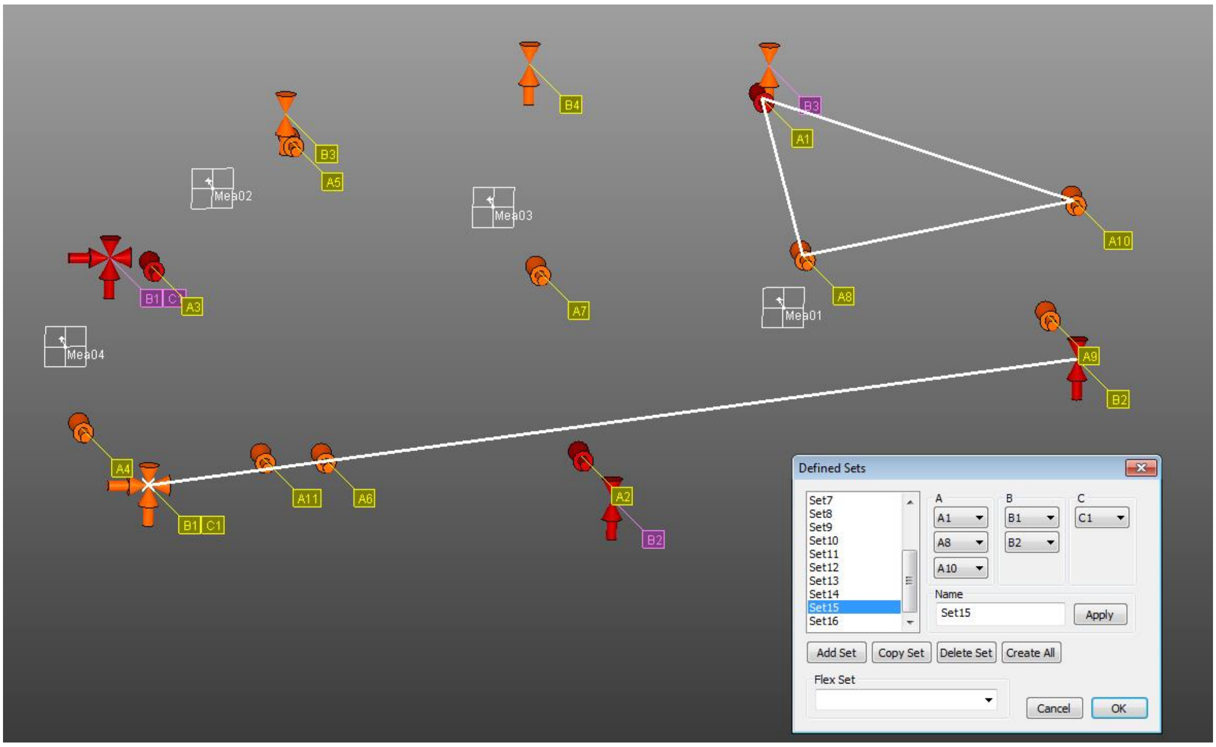


Figure 30: Suggested Flex set in sub-assembly level of Mea01

The suggested Flex chain in Mea01 with each level is shown in Figure 29. According to the calculation behind RD&T, the Y-direction would have the most effective influence on this measurement. So the users changed the Y-points from part to the located fixture in order to avoid any calculation mistake that would cause wrong results. Those points would keep the exactly same coordinates as in parts since the fixture is virtual only and use the copied coordinates from part. This change was just made to test if there was any problem with the locating scheme and the results turned out that it worked as expected. The possible problem that had been detected was about the local point's selection of this Flex functionality as stated.

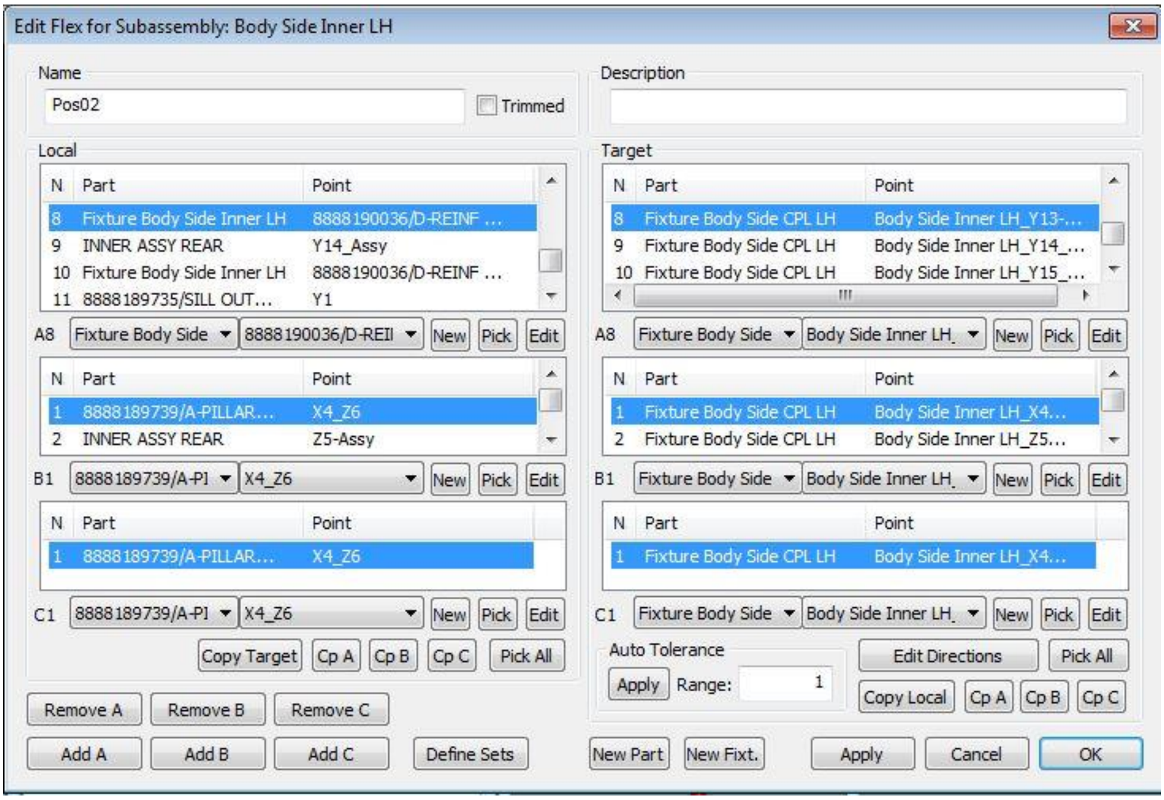


Figure 31: Adjusted Flex set in sub-assembly level of Mea01

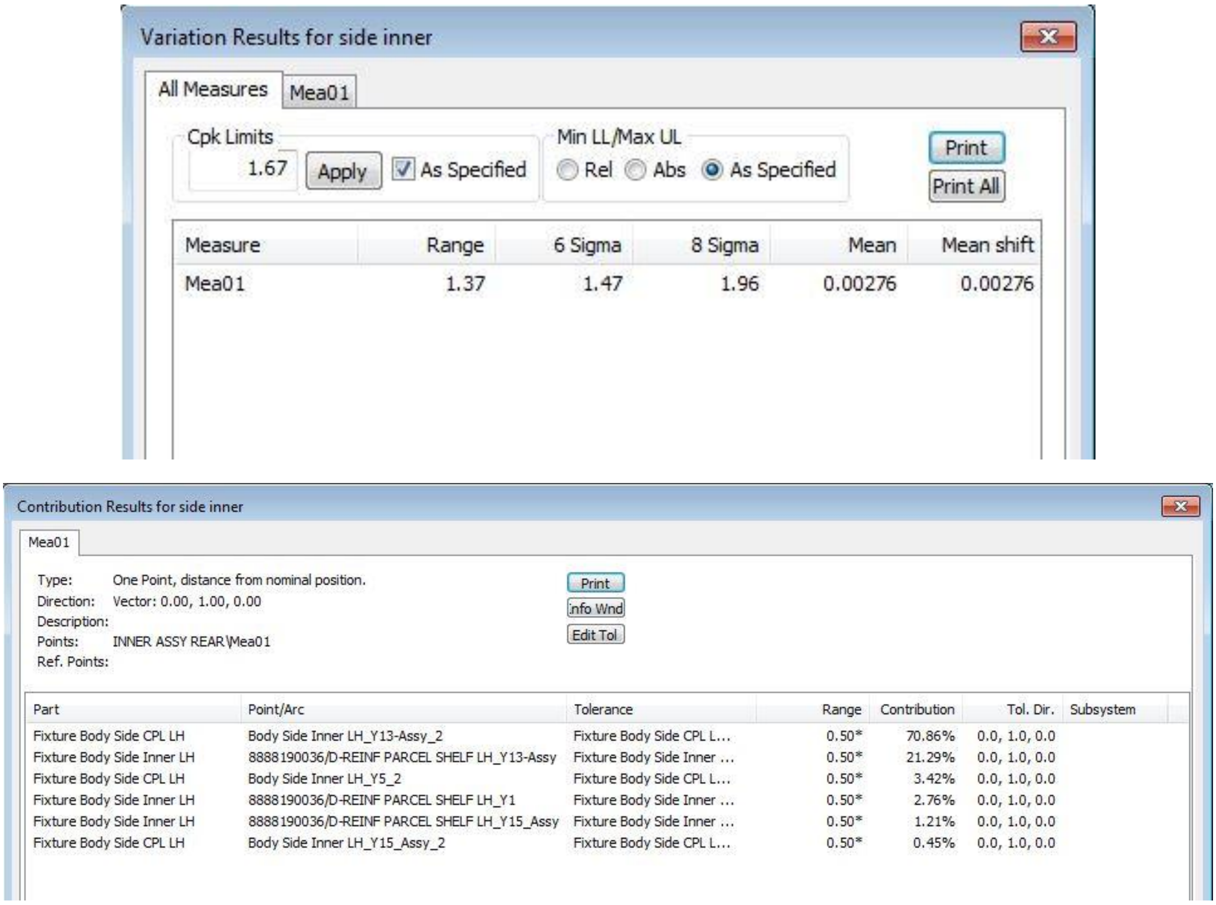


Figure 32: Simulation results of Mea01 after adjusting

This problem had been discussed with Lars Lindkvist, the developer of this software RD&T and also the Flex functionality. It was finally successfully solved in the new version of RD&T. The calculation could be correctly formulated in the Flex model with the same result as in the 6-directions model as can been seen in Figure 32.

After this problem, the authors did several changes in the tolerance chain in order to make the variation and contribution result more realistic and reliable. Measurement tolerances were given for all four measurements. Process tolerances were modified according to the guidance of current employees in DM. The locating tolerances of locating holes and locating slots in each part were defined according to the 3D PMI from Teamcenter and the Volvo standard of general tolerances. The variation analysis results are going to be compared with the 10 sigma result since it is much more realistic in comparison. After these modifications, the two models come with very similar variation analysis result and exactly the same contribution analysis list. The slightly difference in variation result is considered to exist due to value rounding in the calculation, so it could be ignored in comparison. The two results are listed in Figure 33. The contribution analysis lists for each measurement are shown in Figures 34 to 37.

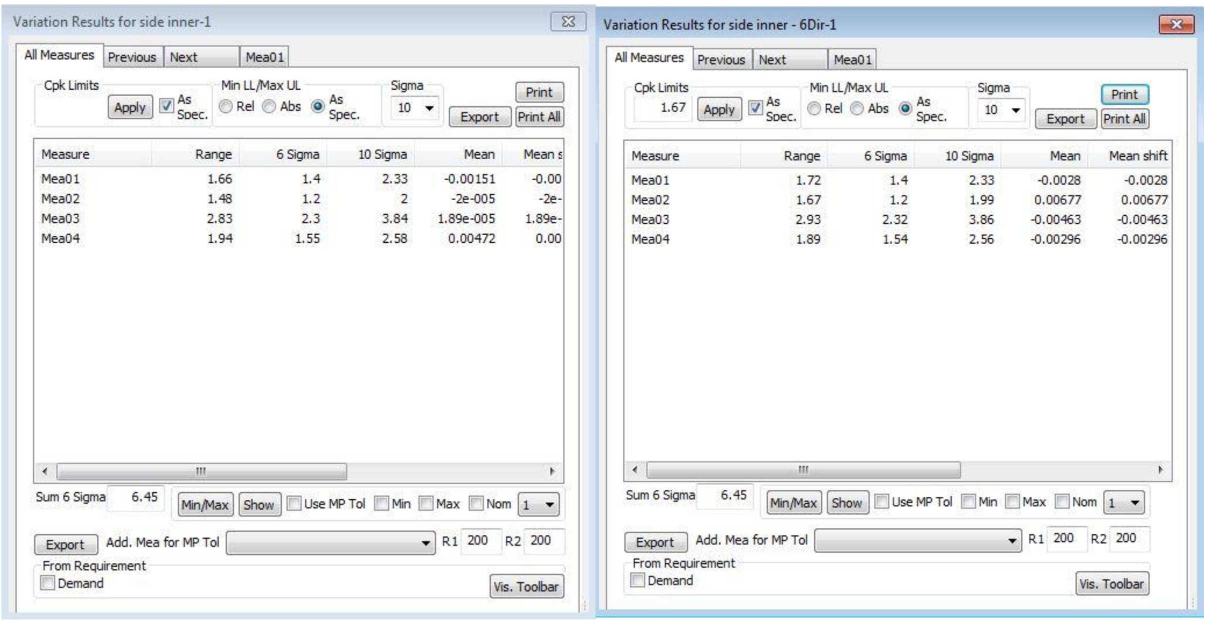


Figure 33: Final variation results of 4 measurements

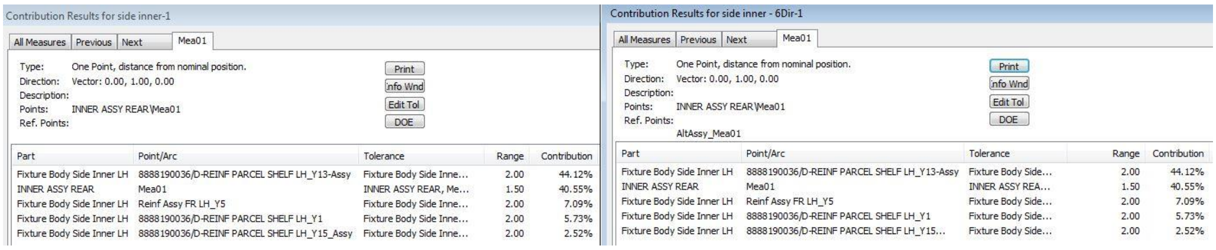


Figure 34: Final contribution list of Mea01

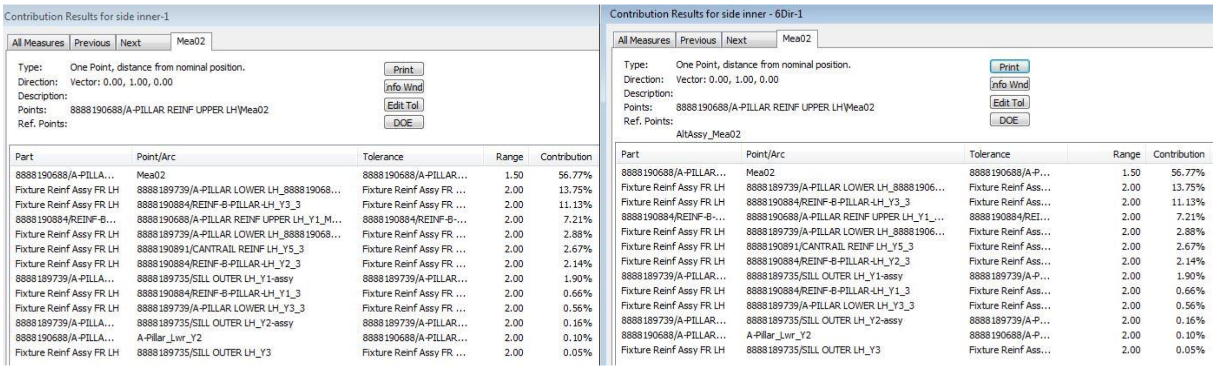


Figure 35: Final contribution list of Mea02

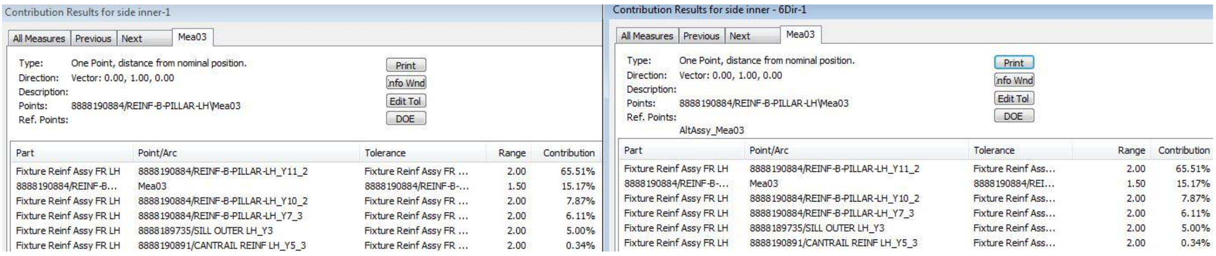


Figure 36: Final contribution list of Mea03

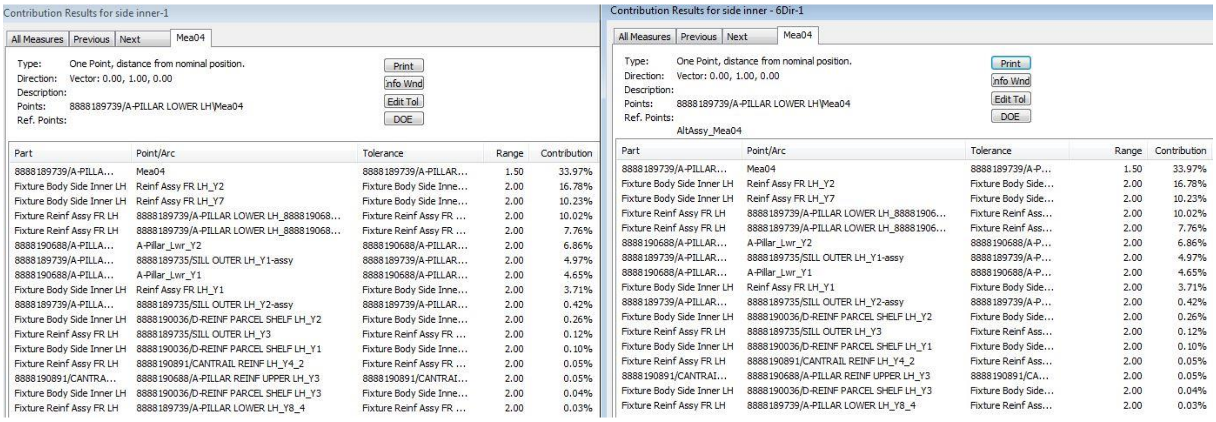


Figure 37: Final contribution list of Mea04

In this new version of RD&T, the Flex view functionality is also improved according to the experience of the authors. All the six points that have been used in each set, as well as in the default set, can be visualized in the window with a triangle presenting the three A points, a line indicating the two B points and one cross representing the C point, as it can be seen in Figure 30. In the current 6-directions modelling, there is no visualization like this triangle in Flex in order to enable users to check the locating schemes. It could obviously improve the accuracy of defining positioning systems and easier for users to present and understand the locating schemes. More advantages and disadvantages would be discussed in Chapter 7.2.

7 DISCUSSION

The discussion covers every stage of the project process leading up to the final models. The chosen methodology and its implementation, and the validity of the results and their effects are covered in this section. Especial attention is been given to explaining the relation between the product development process and the production process in the section 7.3 Production chapter. Finally, further development with regard to RD&T, working procedure, detected problems and sustainability issues are discussed.

7.1 Methodology and implementation

The chosen methodology has been adapted to fit the purposes of this master's thesis and in general has led to satisfactory results both regarding the RD&T models and the conceptual working procedure model. However, even after obtaining good results it is possible to find sources of error or things that can be done better.

For example, when performing an interview, it is important to be aware that there may be sources of error that can give wrong results, in our case, coverage error by making unclear or wrong questions that can have been interpreted differently by the interviewees, this may have given rise to misunderstanding the questions, and making more difficult to compare the results of such questions.

Other sources of error were non-response or no acknowledge on the treated issues by the interviewees that could be taken like general positions which is not necessarily the truth. Interviews are not mathematical methods that give exact results; on the contrary they are based on human experiences that can differ from person to person. To have a bigger range of opinions more interviews should be performed. The authors were limited by time and availability to four interviews and five interviewees.

When analyzing the collected data the two authors were involved but this could have been done better if more people would translate the data in order to avoid subjective interpretations or preconceived notions, like is recommended by Griffin and Hauser [22].

In general and despite the limitations described above, the authors have been able to apply the chosen methodology with satisfactory outcomes.

7.2 Validity of results and effects

Usability analysis

Even though the Flex functionality has not been fully developed yet as stated in the Chapter 6.2, the usability between it and the alternative assemblies could still be compared depending on the user experience of authors in this project.

In the Flex system, only one positioning system needs to be defined with all the support points that would be used in all locating schemes. That means the user only need to choose selected points once in every part and subassembly. While in the current 6-directions positioning system with alternative assemblies, it would require the user to define several 6-directions positioning system as many as the quantity of the required locating schemes. The 6 locating points need to be defined in every positioning system even there would only be one point different from the previous defined positioning system. It would be a repetitive work and would become extremely complicated while there are too much locating schemes need to be tested.

For example, as what is shown in Figure 27, there are 16 different locating schemes in Pos02, the positioning system of the subassembly ¨Body Side Inner LH¨ of the model, including the default set that uses the 6 main points and 16 sets that use some support points. If the user is going to compare the same 17 schemes in current model without Flex, there will be 17 different positioning systems in this subassembly. It would not only cause duplicated work in defining different positioning systems, but also result in inconvenience in changing different systems by go into editing positioning system window in order to compare. To avoid mistakes, users need to have several lists of points in different positioning system to check. This is very inconvenient and could not ensure the accuracy.

The visibility perspective is one of the most valuable aspects of this Flex functionality. First of all in Flex about visibility is the Flex view window. This window can be found in a button that is located in the bottom of the VRML view, as what can be seen in Figure 38.

Figure 38: Flex view button in VRML view

In this window, different Flex chains would be displayed with each set that has been defined by users. Every set is marked with a full green round, which is easy to see in Figure 38 and easy to be distinguished from the positioning systems. The chosen Flex chain by each specific measurement could be shown automatically after choosing ¨Find Suitable¨ in the measuring point, as in Figure 39. User could go into this window end edit each positioning system and measuring point directly by right clicking on the name.

Besides, there is another advantage of this Flex view window about visualization. There would be a triangle shown in the model that highlights the three A-points that have been used in every specific set, and one line indicates the two B-points as well as one C-point, as what could be seen in Figure 40. This function could be realized easily by clicking on the name of the sets from the Flex view window or the define sets window. This is a valuable function that enables users to check the locating schemes directly and easy to detect any possible problem. It was very common that in the alternative assemblies in 6-directions positioning systems; users need several lists of the name and position of points in different systems. There is no need for such a kind of list in Flex, which makes it much more user-friendly.

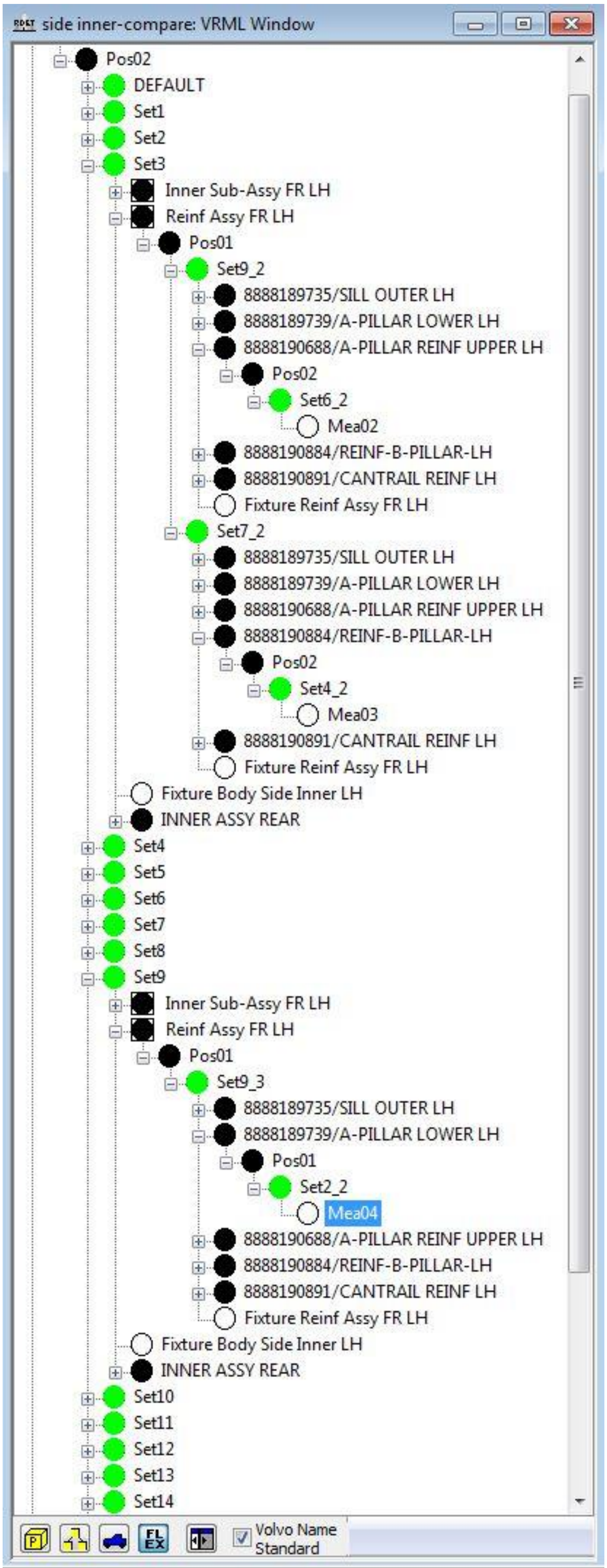


Figure 39: Display of different measuring points in Flex

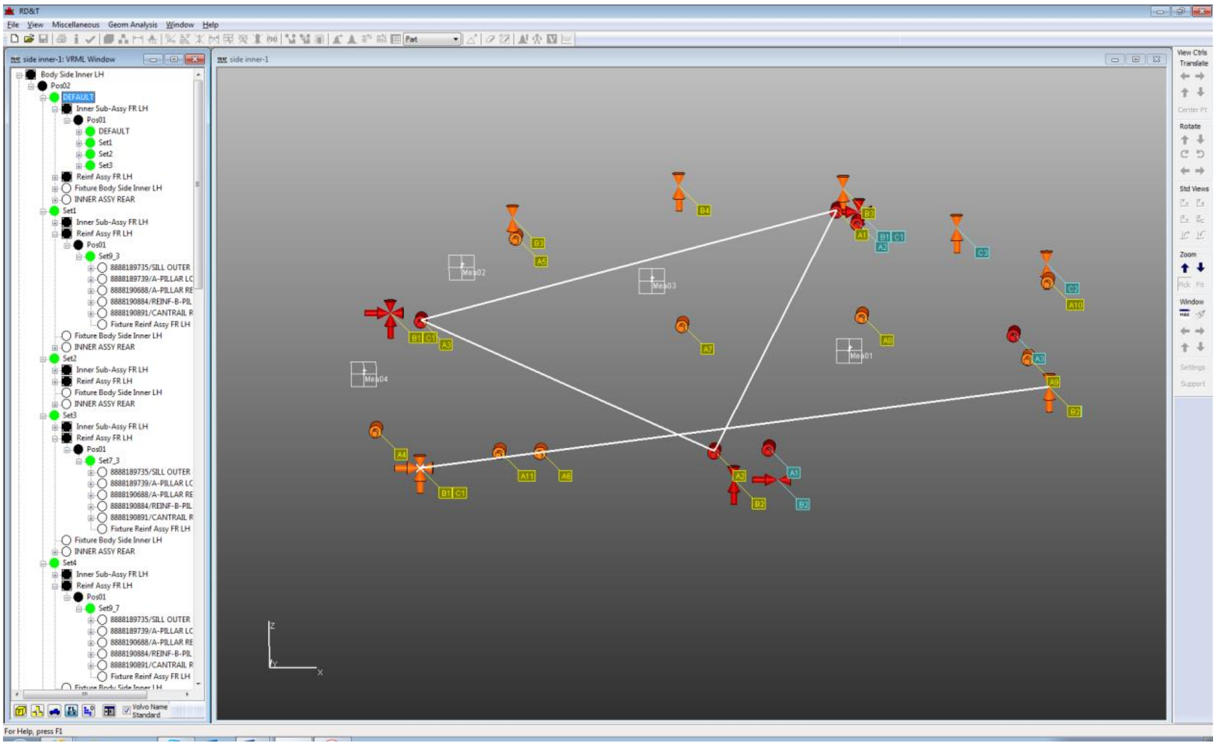


Figure 40: Display of the Flex triangle

The convenience of Flex could also be experienced from changing points in the positioning system. If users want to change a reference point that has already been defined in the positioning system, from one point to another, it would be required that users need to go into every poisoning system that enclose this reference point and change it manually. Then the convenience of only one positioning system in Flex could be seen because it could be done just by changing it once in defining, and all sets would be automatically changed corresponding to that reference point. In the alternative assemblies of 6-directions positioning system, users need to check which system use this point and go into every positioning system that have been detected using it and change it several times. It would require duplicated work and has risk of missing any positioning system that has used this point.

The last but not the least benefit of Flex, is that it could suggest the most realistic locating schemes in each level for the users. This is the intention of the ¨Find Suitable¨ button in measurements. The calculation behind would take the locating points that have been defined with the closest mass center to the measuring point, which also are the most possible choices in the reality. To analyze the reliability of the Flex result, measuring data from production is required in order to make comparison. Unfortunately, the model that has been used in this project is still in the developing phase and expected to be put into real production in 2017. Also there is still no real production in CEVT currently that could support this project with real measuring data. This advantage point could be verified by further investigation or thesis studies.

The considered disadvantages of Flex are mainly in two points. The first is that, to enable the program to choose the most suitable set in each level, it is required to have many sets and user’s experience about where to put locating points. The ¨Find Suitable¨ function would only choose the most realistic set from the sets that have been defined before. The second one, Flex functionality would be considered valuable with several support points. If there is only one support point in a specific part, the benefit of Flex would not be seen as obvious as with several support points.

7.3 Production Chapter

There is a clear connection between product development and production. This section is aimed to describe this connection in terms of manufacturing capability, time balancing and quality reliability at CEVT.

7.3.1 Manufacturing capability

Manufacturing capability is defined as the output level from production system. It could be affected by cost, quality, delivery reliability and time, performance, flexibility, etc. [23]. Simulation tools could contribute to the quality and time related cost by using mathematical function, like Monte Carlo simulation [24].

In this thesis work, the Monte Carlo simulation is used as the mathematical function behind in RD&T to calculate the variations. Not only it is used in the 6-directions locating system, but also used in Flex method. Since both locating systems used the same 3-2-1 principles and have taken exactly the same amount of runs and cpk (Process capability index) in the Monte Carlo calculation, the effect in manufacturing capability perspective could be considered as the same.

7.3.2 Time balancing

Time is an important factor in planning, control and decision making in the whole product emergence process among manufacturing companies. This kind of process includes product development, process planning as well as production. For instance, time data could be used to evaluate the cost in production and the process capability in product development phase [25].

Since this thesis is based on the dimensional management daily work in product development phase, the influences are related mainly to the time data management in product development. As demonstrated previously, this Flex functionality is much easier for users to build locating systems and avoid duplicated work in defining reference points etc.; it significantly saves a lot of time in R&D process. Meanwhile, since Flex enables user to define the most robust locating system, it could help to decrease the possibilities to revise the dimensional management work and make the internal collaboration in the organization more smoothly.

7.3.3 Quality reliability

Quality control is a procedure that aims to meet the requirements set by customers. The main tool used in here is sampling inspection collected during manufacturing. Effective quality control could contribute to prevent defectives and help to evaluate the production process [26].

According to the interview with ME, the quality control in CEVT is realized by collecting samples to measure. There is a rule implemented in collecting samples for months, in order to check if the line coordinates smoothly. Fixtures would be used in this process to check if the fixtures are able to manage the requirements of quality. This verification process measures holes and contact surfaces that have clamps or located items on. The quantity of samples would be 15 parts. The quality in CEVT is considered reliable since the concepts corresponds to the definition of quality control and the verification process supply certain amount of samples to support quality control. According to the interpreted interview results, the Flex function is considered to give better prediction in production and could be the key to solve the debates on the production system calculation. It would give better support to achieve higher quality reliability.

7.4 Future development

The recommendations for the future work are divided into four perspectives: RD&T software, working procedures, dealing with problems and sustainability; which are presented in the following sections.

7.4.1 RD&T

To verify the reliability of the Flex functionality in RD&T, further investigation in comparing real measuring data corresponding to the measuring result of ¨Find Suitable¨ function in Flex should be implemented. According to Lars Lindkvist, the developer of RD&T, Flex functionality was designed to suggest the most realistic result in measurements. In reality, this benefit should be tested in order to have data to support it. This work could not be done in this thesis since no model has been into production phase yet at CEVT.

Besides, during this thesis work, authors have experienced this new functionality and there are some suggestions from user experience perspective for developing. Currently, each Flex set can only be edited from the editing positioning panel for each part or subassembly. It would be easier if users could go into the edit set panel directly from the set name in the Flex tree. Also, the Flex tree expands automatically to the point level when clicking on editing point or Flex view button. Then there are too many things in the Flex tree that can cause inconvenience for users.

7.4.2 Working procedure

The conceptual working procedure model that have been presented in Chapter 6.1.1 shows the reality the authors have found through the collected and analyzed data from interviews and observations. In order to validate the veracity of the model some testing in form of surveys and/or focus groups is suggested for future thesis works. Of this two methods, the second one is probably the most appropriate to use for testing the model.

A focus group interview is an unstructured method that can be used to verify and evaluate the relevance of the working procedure model. In order to focus the discussions on the relevant topic or theme, a person can act as moderator and lead the discussion when necessary, without asking leading questions [27]. Members of this focus group should include people from the departments so called main actors but even involve secondary actors to get an even bigger perspective. Consider the possibility to integrate the Chinese counterpart via Skype or some other IT tool to the focus group.

7.4.3 Dealing with problems

A first step to start dealing with the detected problems is to be aware of their existence. The authors have presented the improvement potentials in the product development process in Chapter 5.3.4.1 divided in six main groups of detected problems.

The bigger problem may relay in collaboration and communication between the actors, this due to the fact that CEVT is a quite new company that still lacks documented common working procedure processes. Educating the employees and learning from current projects may be the key to overcome these problems. Education in different subjects as collaboration, common procedures, language, cultural differences and sustainability are as important as mastering the RD&T program could be. A better understanding of the different philosophies between Sweden and China could lead to avoid misunderstandings and unnecessary expenses.

As soon as the first project is released, a common working procedure process based on the experience gained from the projects should be developed, taking into consideration the detected problems and the solutions adopted, in order to get all actors working in the same way in the future projects.

In order to avoid losing information gained from the projects, it is recommended that the PLM system incorporates or includes a folder for Knowledge management documents where all new knowledge gained from the projects can be storage for further use.

7.4.4 Sustainability

First of all it is extremely important to create awareness among the employees both in Sweden and China about sustainability matters and to educate them to be a part of a common effort to diminish the environmental and social impacts caused by all human activities and to apply this new eco-friendly point of view into their daily work.

The execution of a life cycle assessment (LCA) is recommended as soon as the first project is released in order to map out the inputs and outputs of material flows and the environmental effects through the whole life cycle and continue exploring and experimenting with new lighter materials to implement in future projects in order to reduce the vehicle’s weight.

Start investing in new eco-friendly technologies and renewable fuels is a long term investment that is strongly recommended and could place the Lynk & Co brand at the forefront of the automotive industry with a clear green image.

8 CONCLUSIONS

This thesis work has been aimed to test and detect problems in Flexset functionality and to investigate how to implement it in a specific work environment, as well as to define the current working procedure process of the product development of body in white at CEVT. To detect the competence of Flex function, two models were built based on a specific sedan car designed by CEVT in current 6-directions locating system and Flex locating system respectively and they were compare in usability perspective.

Self-studies were implemented in the start phase of this thesis work, and the total methodology used was designed according to the product development process by Ulrich and Eppinger [1]. Customer needs were detected by interviewing engineers from different roles and observations made during the daily work in CEVT. After collecting raw data, these were analyzed and interpreted by using customer data template, KJ and AIM method to identify customer needs, factors and problems in order to be able to produce a process specification that would contribute to define the working procedure and create a conceptual model of the current product development process of body in white.

Besides, the improvement potentials were detected from the working procedure as well as in the modelling methods in RD&T. The comparison results between the 6-directions locating system and the Flex locating system assist the competence of Flex functionality in the part or sub-assembly with several support points. Some suggestions from user experience perspective have been given in order to help improving before formally implementation. To help users to learn it easily, an instruction was formalized with explanations in detail. Even though there was a significant difficulty during model building, which had stopped the thesis process once, the authors helped the developer of RD&T, Lars Lindkvist to conquer the problem and made this thesis closed properly with satisfied results.

9 RECOMMENDATIONS

The satisfactory results obtained during the usability comparison of the RD&T models make possible to recommend the implementation of the Flexset functionality into the dimensional management department in R&D phase when this function has been verified with measurement data collected from production. According to the results from this master's thesis work, the advantages in Flex when calculating the reference locating system with several support points on the part or sub-assembly, such as bumper, have been clarified compared to the current 6-directions locating system.

A future study about verifying the reliability from production perspective could be initiated. This functionality could significantly save time cost in the R&D phase, as well as provide more reliability for the reference system defining theoretically. Since the instruction of this Flex functionality has been formulated by authors clearly, the implementation of it would be very easy and quick among current employees.

The presented conceptual working procedure model reflects the actual situation during the product development process of body in white and it is the authors' recommendation to test it in order to validate its veracity.

The detected problems should be taken into consideration and actions to overcome these ones are necessary, see chapter 7.4.3. Start the development of a common working procedure process that can be adopted by all CEVT employees is a priority and strongly recommended as soon as the first project is released.

Finally, increasing the sustainability awareness inside the company and mapping out the environmental impact from cradle to grave of the new Lynk & Co vehicles in order to find alternative solutions to diminish these ones is recommended.

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APPENDIX

APPENDIX A – INTERVIEW GUIDES

SEMI-STRUCTURED INTERVIEW GUIDE: DIMENSIONAL MANAGEMENT

Opening question

1. Could you present yourself and describe your responsibilities at CEVT?
2. Could you describe the responsibilities in the sub groups inside DM department?

Body

<u>Overall process</u>

1. Can you give us an overall description of the working process in Dimensional Management?

<u>Connecting Dimensional Management with other departments at CEVT</u>

External collaboration

1. How does Dimensional Management collaborate with other departments? Do you have any clear work procedure or documented material of it?
2. If there is no clear work procedure, can you describe the connection in detail?
3. About the current process, how does communication between these departments work?

Internal collaboration

1. How often do engineers from your group and Emilie's group communicate? Do you have meetings? (Formal or informal)
2. Is there any communication problem even in the internal sub departments in dimensional management? How do you handle it?

Common questions external and internal

1. Do you have any recommendation to improve current workflow between departments?
2. What are the most common conflicts or problems in these discussions? How do you solve it?
3. Is there any collaboration between DM department and China plant? Do you have any problem in this process?

<u>Improvement potential</u>

1. Do you think there is a future improvement potential in this communication process?
2. Is there commonly any information loss in collaboration with other departments like Manufacturing Engineering (ME) or System Engineering? If so, how do you solve it?
3. How do you decide tolerance with ME department? If you have different opinions, how do you handle it?

4. Is there any information loss in the communication with China? What do you think could help to improve it?
5. How do you handle the cultural difference between Sweden and China in collaboration such as hierarchical organization structure against more flat structure?

Capability

1. How do you handle the difference between simulated geometrical variation and realistic variation in DM? If there is any unpredicted variation, how do you handle that?
2. How do you (or who) decide the reference system? Is it any specific rules to follow? How to combine the theoretical reference systems with practical needs?
3. Do you think Flexset function would bring more advantage or disadvantages into production than the original methods? Why do you think so and in which area?
4. Compare Flexset in rigid model with compliant model, what do you think would be more profitable (good balance between the cost and profit)? Why does CEVT only use rigid model currently?
5. How do you think could Flexset affect current work procedure in DM?
6. How do you think the future of geometrical assurance at CEVT would look like? Would eventually compliant model replace or complement the current models?
7. How does the time plan go through inside DM as well as working with other departments? Is it always on time or is there any problem in this aspect? If not always on time, what could be the main reason?

Environmental issues

1. Which department alternative is responsible for taking into consideration the environmental issues regarding sustainability in order to diminish the impact on the environment?
2. Do you think there is any improvement potential in this matter from your department perspective?
3. What about the working environment? Which department is responsible for that?
4. Do you take any ergonomic design perspective in the factory level into consideration?

Closing question

Do you have something else you would like to add?

SEMI-STRUCTURED INTERVIEW GUIDE: PRODUCTION DEPARTMENT

Opening question

Could you present yourself, what are your responsibilities at CEVT?

Production general

1. How does production/manufacturing function of CEVT works without a real production site in Sweden?
2. Is there any collaboration in production with Volvo or Geely? If yes, how does the collaboration work?
3. Currently, there is a production site of CEVT funding in China. How would the production department collaborate with the local production department in China?
4. Do you do all pre-assembly by yourself? If not, what kind of pre-assembly do you outsource?

Body

Connecting PD & PE

1. About current process, how do production sites receive the information from product development?
2. Is there any documented material that in a systematic way describes or give guidance about this information process?
3. How often do engineers from these two sections have meetings and exchange information?
4. What is the most common conflicts or problems in these discussions? How do you solve it?
5. How do you decide tolerance with product development department? If you have different opinions, how do you handle it?
6. How do you (or who) decide the reference system? Is it any specific rules to follow? How to combine the theoretical reference systems with practical needs?
7. What do you think is the future improvement potential in this communication process?
8. How does the time plan go through from product development to production?
9. Is it always in time or there is any problem in this aspect? If not always in time, what could be the main reason?

Improvement potential

1. Work efficiency & accuracy
   a. How do you measure the work efficiency, accuracy in production?
   b. Is there any specific KPI related? How often do you measure it?
   c. How do these KPIs been decided?
2. Information loss
   a. Is there commonly any information loss in collaboration of production with other departments like design or geometry assurance?
   b. Is there any information loss with Chinese production department?
   c. What do you think could help to improve it?
3. Cultural difference

   a. How do you handle the cultural difference between Sweden and China in collaboration such as hierarchical organization structure against more flat structure?

Capability

1. Machining capability
   a. How do you measure/control the capability of machining in product development?
   b. Is there any method used in it? Do you have meetings with PD employees?
   c. If there is any conflict in it, how do you solve it?
2. Sub system
   a. How does sub system been decided? Are you involved in this process?
   b. How do you apply it in reality?
   c. How does it support production?
3. Rigid & Non-rigid
   a. Is there any difference in production and assembly with the rigid and non-rigid body design?
   b. What are the differences and why?
4. Simulated & realistic geometrical variation
   a. How does simulated geometrical variation differ from realistic variation?
   b. What could be the main reason for that?
   c. If there is any unpredicted variation, how do you handle that?

Current against Flexset and Compliant modelling.

1. Advantages and disadvantages in
   a. Accuracy versus time and money.
   b. Customer segment you are reaching, get the right balance
   c. Time/human cost/profit VS. quality/customer satisfaction/delivery/lead time
   d. Would the new model required adjustments in production? Cost, new machinery?
   e. Do you think Flexset function would bring more advantage or disadvantages into production than the original methods? Why do you think so and in which area?
2. Compare Flexset in rigid model with compliant model, what do you think would be more profitable (good balance between the cost and profit)?

Quality inspection

1. How do you measure the quality in production?
2. Do you have quality inspection after every pre-assembly process as well as the final assembly?
3. What could be the main quality problem in production that could be related to product development?

Maintenance

1. How do you do maintenance in production?
2. Is it preventive maintenance or a combination with other kinds of methods?

Environmental issues

1. Is the company taking in consideration sustainably matters in production in order to diminish the impact on the environment?
2. What about the working environment? How do you deal with high levels of noise at the factory, safety precautions, and exposure to dangerous substances?

Closing question

Do you have something else you would like to add?

SEMI-STRUCTURED INTERVIEW GUIDE: SYSTEM ENGINEERING

Opening questions

1. Could you present yourself and describe your responsibilities at CEVT?
2. In a few words, can you describe what the System Engineering department does?

Body

Connecting System Engineering to Dimensional Management

1. How does System Engineering collaborate with Dimensional Management? Do you have any clear work procedure or documented material of it?
2. If there is no clear work procedure, can you describe the connection in detail?
3. About the current process, how does communication between these departments work?
4. Do you have any recommendation to improve current workflow between the departments?
5. What are the most common conflicts or problems in these discussions? How do you solve it?
6. Is there any collaboration between System Engineering department and China plant? Do you have any problem in this process?

Improvement potential

1. Do you think there is a future improvement potential in this communication process?
2. Is there commonly any information loss in collaboration with other departments? If so, how do you solve it?
3. Is your department involved in deciding tolerances with DM department? If you have different opinions, how do you handle it?
4. Is there any information loss in the communication with China? What do you think could help to improve it?
5. How do you handle the cultural difference between Sweden and China in collaboration such as hierarchical organization structure against more flat structure?

Capability

1. How does System Engineering handle the work between different departments?
2. Is System Engineering involved in deciding the reference system? If yes, are there any specific rules to follow? How to combine the theoretical reference systems with practical needs?
3. Do you think Flexset function would bring more advantage or disadvantages into production than the original methods? Why do you think so and in which area?
4. Compare Flexset in rigid model with compliant model, what do you think would be more profitable (good balance between the cost and profit)? How would it affect the work of System Engineering?
5. How does the time plan go through inside System Engineering as well as working with other departments? Is it always on time or is there any problem in this aspect? If not always on time, what could be the main reason?

Environmental issues

1. Does your department take into consideration environmental issues regarding sustainability in order to diminish the impact on the environment?
2. Do you think there is any improvement potential in this matter from your department perspective?
3. What about the working environment? Do you take any ergonomic design perspective in the factory level into consideration?

Closing question

Do you have something else you would like to add?

SEMI-STRUCTURED INTERVIEW GUIDE: DESIGN

Opening question

1. Could you present yourself, what are your responsibilities at CEVT?
2. Could you present the work procedure and collaboration of Design department with other departments?

Body

Connecting Design & Dimensional Management

1. How does your department collaborate with dimensional management department? Do you have any clear work procedure or documented material of it?
2. If no clear work procedure, can you describe the connection in detail?
3. About the current process, how does Design and Dimensional Management communicate?
4. How often do engineers from these two sections have meetings and exchange information?
5. Do you have any recommendation to improve current work flow between these two departments?
6. What are the most common conflicts or problems in these discussions? How do you solve them?
7. Is there any collaboration between design department and China plant? Do you have any problem in this process?

Improvement potential

1. Do you think there is a future improvement potential in this communication process?
2. Is there any communication problem even in the internal sub departments in design department?
3. Is there commonly any information loss in collaboration of Design with other departments like Dimensional Management or Manufacturing Engineering (ME)? If so, how do you solve it?
4. Is there any information loss in the communication with China? What do you think could help to improve it?
5. How do you handle the cultural difference between Sweden and China in collaboration such as hierarchical organization structure against more flat structure?

Capability

1. Do you need to do any calculation about dimension data or tolerance data? If so, how do you do it? If not, do you need to change it sometime or give any feedback on it?
2. Could rigid and non-rigid models used in dimensional management department affect your work?
3. Compare Flexset in rigid model with compliant model, what do you think would be more profitable (good balance between the cost and profit)?
4. How do you take the variation between design and production into consideration? Do you have any variation between design and geometry?

5. We are going to test Flexset function in RD&T. Do you think this work could contribute to the work in design department?
6. Do you think Flexset function would bring more advantages or disadvantages than the original methods? Why do you think so and in which area?
7. How does the time plan goes through from design to dimensional management? Is it always on time or is there any problem in this aspect? If it is not always on time, what could be the main reason?

Environmental issues

1. Is your department taking in consideration sustainability matters in design in order to diminish the impact on the environment? Do you think there is any improvement potential in this matter from the design perspective?
2. What about the working environment? Do you take any ergonomic design perspective in the factory level into consideration?
3. Are you taking in consideration factors like high levels of noise at the factory, safety precautions, exposure to dangerous substances, etc. into your design?

Closing question

Do you have something else you would like to add?

Appendix A – Interview guides

APPENDIX B – CUSTOMER DATA TEMPLATE

Color coding	System Engineering (SE)	Design	Dimensional Management (DM)	Manufacturing Engineering (ME)
Question/ Prompt	**Customer Statement**	**Interpreted Need**	**Problem identification**	**Understanding working procedure**
Working procedure	System engineering is the spider in the complete development net.			System engineering coordinates the work between different departments: design (styling), ME and DM.
	We (SE) are responsible for delivering the actual CATs model drawings and to do this we need help from styling and manufacturing engineering and also dimensional engineering I would say, but we are responsible for delivering the data.			System engineering is responsible for delivering CAT drawings and data.
	There is another player that we should put in there: the attributes, we have packaging department that is helping us with putting everything together with other pss, we have safety of course...			Other actors: Attributes, packaging department, safety.
	There is a lopping ongoing all the time...We have UV concept we have V0 V1 V2 FTG I would			5 loops: UV, V0, V1, V2 and FTG, then final release.

Appendix B– Customer data template

Working procedure	say it's five loops, and of course when we have reach this FTG loop which is the last official one we also release finally the drawings.			
	The system engineering is responsible for the product until three months after JOB1 or start of production, things that happen after that maybe if there are any changes that have to be done after that, and then it is ME that is responsible for that.			System engineering is responsible until JOB1 or start of production, then ME takes over.
	We have of course legal requirements we have to follow.			Another actor: Legal requirements
	I work as an interface between the styling department and the engineering department, vehicle integration of packaging department and the system engineers and so when I'm in a project I work together with the packaging department to help the design and packaging work together to start with rough targets and we try to find design process and later on in the process is working in individual parts			Studio engineers work as an interface between styling and system engineers.

Working procedure	together with the system engineers.			
	I have lot of meetings to go to and it's always times when you have to balance it so if we had a bigger budget and more studio engineers around then it would be good to have more. We are slightly stretch I guess. In the early stages of the project normally there is only 1 studio engineer but after the DSM file as we go into the technical input of the individual part normally you have 2 or 3 studio engineers for the exterior and 2 or 3 for the interior, we split it up that way that you are interior and exterior styling and they work together but separately and it's the same over here our interfaces are split up into interior and exterior.	Desire to increase the amount of studio engineers to balance the high workload better.	High workload	Interfaces are splitted up into interior and exterior. 2 or 3 studio engineers for each interface.
	We are only interested in the gap and the flushes and then if we start having conflict that we don't want to have what the result is then we might go back and ask again can you double check it.			Design is only interested in gap and flush data for styling.
	...we stuck with the			Tolerances may

Working procedure	tolerances we might then ask if there's not another way to reduce the tolerances but it's not our job to do that is the system engineer's job to try to reduce the tolerances.			affect styling work but SE takes care of tolerancing data input not design.
	We have a design department that is called the design quality they take that ...it's like the perceived quality at CEVT but it's thinking about the design aspect of it, they normally look at the models throughout the design process and then also very much at the end when start producing cars to try to see where things are going wrong and if it's to do with built quality, variations in building quality then maybe there are ways to improve that for the next car, you can try to design things that are less sensitive for these tolerances.			Design quality inside design department, deals with variation in quality from design perspective and implementing improvements to next projects…
	My group can be called dimensional engineering and the other one PQ, the PQ they set up the final demands for the car, what kind of normal gap and flush we should have, the visual look of the car and we calculate if			2 groups inside DM department: DE (dimensional engineering) and PQ (perceived quality). PQ sets up the final demands and DE makes all calculations that deal with

Working procedure	we can achieve the final demands, if the gap is ok and the flush is ok, PQ they set up the demands and we calculate if it's possible to fulfill that. PQ has several other things like surface finish and illumination and we also not only do calculation for PQ demands, we also do for function demands, clearance, package so we calculate everything on the car that have tolerances on if there's a small gap somewhere.			tolerances.
	Of course we work parallel, if we see that this is not possible with the tolerances and how build the car together today then we have these cross-functional team meetings.			DE and PQ work parallel and in cross-functional team meetings.
	First we try to find the robust system with less variation as possible for each part that affects the PQ demands for instance a lamp, a hood when we have set up the RP system and the tolerancing we create like a GD&T document, pre-drawing you can maybe say and that document we communicate with system engineers as			DM creates a GD&T document or pre-drawing and shares it to SE, come to an agreement and put the pre-requisites in the model, make calculations based on PQ demands.

Working procedure	design department and then we have to agree in this is the best way we can achieve this tolerances, when we have done that we put those pre-requisites as well in the RD&T model, we build up the model according to those systems and then we start to calculate the PQ demands so then we compare the PQ demands with our figures and see if it is ok or not.			
	...then we just check our pre-requisites on drawing. We don't make the drawings we check those, it is design, not styling the system engineers.			DM is not responsible for drawings, SE department is.
	In this cross-functional team it is, we have. Manufacturing is also part of that, they can say what they think about it, and if they don't think that the system is good enough they need to tell that. So they have to be a part of it because they later on in the plant, they have to make sure that we can achieve.			Cross-functional team with ME.
	The system engineers, design engineers, we include them in			Common meetings with system engineers and design

Working procedure	those meeting also, they are responsible for the part so, that is our main customer I would say because it's their part and we make the RPS system for their part to make it to fit in the car and also there is some other needs, we have this site where they can add a job request from us.			engineers. They are consider the main customer for DM.
Collaboration between departments	First we (SE) produce some parts then Dimensional Engineering will start looking into the first part we have produce then they			SE produce parts, DM and ME take care of geometry assurance (locating holes and slots, support points...) and give feedback to SE which is implemented to

Collaboration between departments	together with ME suggest where we should have for example location holes for guiding the part normally one hole and one slot when it comes to sheet metal parts, then we have some support points, together with ME they try to find out where they should be and then we will get that feedback to the system engineering then we will implement this to the drawings actually in the 3D PMI we'll implement directly in the models.			drawings.
	It's happening through meetings or we just get some proposal when we have produced the first part. Sometimes there are problems because we would like to move some points or things like that then of course we have meetings together with them also.		Geometry assurance disagreements between SE and DM and ME could occur.	Meetings start after the first part is produced.
	I would say it works quite good actually, there is a little bit differences between sheet metal parts and purchased parts...sometimes they (DM) have some ideas about how we should change it compared	Avoid disagreements between suppliers and DM by giving clear instructions to the suppliers from the very beginning.	Sometimes there are disagreements between DM and suppliers. Extra loops could be generated.	Contact with suppliers.

Collaboration between departments	what the supplier has suggested actually there is a little loop there, mostly I would say quite a short loop the supplier normally change the first setup to what DE actually proposed.			
	I would say, it can be some conflicts when it comes to suppliers because sometimes they have already started their measuring fixtures things like that.	Better communication with suppliers.	Suppliers start working without approval.	
	Normally is the system engineering and vehicle integration that talk directly to the dimensional management team and then they provide us with tolerancing and feed and flush for the product to perceived quality department and we implement that in form of outstanding models...but we don't have any direct contact with GD&T department.			No direct contact with DM. SE and vehicle integration manage contacts with DM and provides data to design.
	We have several phases of technical input which includes thing like geometrically dimensional tolerancing so at the beginning is very rough. Then the process moves on			Several phases of technical input before releasing styling data to SE, more detailed technical input comes in, changes are made in agreement with

Collaboration between departments	and we release styling data and the engineers look at the new styling data and then fine tune the technical input so the more detail the styling data the more detail the technical input can be also and when the technical input is delivered then we agree with the system engineers what we are going to follow and we want to change and then we move into the next styling gate.			SE until moving to next styling gate.
	We have weekly meetings normally...I call development system engineers and packaging engineers to the meeting and they are therefore to raise an issue they see with styling model and styling have new ideas they want to put forward and arise these issues and they send them away to do the investigations.			Weekly meeting between studio engineer, SE and packaging engineers. Main point of these meetings is to arise issues regarding styling.
	I'm more an interface to make sure that we both are talking about the same products because is very easy in a project that stylists they want to do one thing and the system engineers want to think about what is cheap and easy to manufacture,	Studio engineer needs to mediate between stylists and system engineers.	Different perspectives between stylists and system engineers.	Studio engineers act like an interface between styling and SE.

Collaboration between departments	I have to try to find a way to get to the same point.			
	I think if we all work to the process that we have define for us it would be very good a chance to be very streamlined but as we are quite young as a company people are coming in and not working to the same process, some come from Volvo, some come from Saab, some come from other places and they are coming and they work their own way and there is no continuity there is not history to say how things were done before, we all have to learn and each project and co-project are quite young as well, each co-project that comes through goes more smoothly, I think it's just the case of time and following the process that we have it should work but we need to teach every one.	Need for education in common procedures.	People come from different backgrounds and work in different ways. Since the company is still young, there is not a common way to do things.	
	The stylists they always want to have free hands to do what they really want and the engineer wants to always have control. They see a new concept car and they	Need to restrain the stylists according to factory restrictions and budget as well as to encourage engineers to take risks.	Tendency to do things the way it has always been done.	

Collaboration between departments	want to make something look like that and that is restricted by reality of what's in the factory and what the budget says so stylists need to be sometimes restrained and I have to help them in that process together with the project lead at decide, his responsibilities to pass these issues and I have to raise the issues to the project leader and the engineers I think they sometimes need to be encouraged to take a bit more chances and sometimes they have so much work that just want to do what they've done before and I have to force them to look in another way outside the box.			
	We still have different philosophies because when we work, we would go little bit in one way, and they will be in one way, and sometimes it would be a discussion, what is the right way. Volvo say their way is the right way, we say our way is the right way. That means we need to judge and make the best of the situation. We are		Different philosophies of people who come from different industry background and places	

Collaboration between departments	suppliers to Volvo when comes to the datum and CMA, and Volvo should execute for their cars and also CS11 is responsible for. But how far are we suppliers or we responsible? Because sometimes Volvo thinks that this is the way it should be, and we say no, we are the developer of this vehicle and we want it to be in this way.			
	ECR, the engineering change request. So when it comes to the geometry, they are supposed to send it to us, not always work, sometimes it goes directly to R&D. Then we bring it up with R&D. From our side, R&D, we have something we call it issue tracker. So let's say that production right now should say the problem with the car, and you say that this is a design issue. So they should write an ECR to us, sometimes we don't need it, we just did it by phone call if it is easy to understand, it's very clear. We get this, we write an issue tracker, which goes direct to the design engineers that	Need to be adjusted according to where they are in the process		Official way: ECR-issue tracker-PCR. So it's very important that we don't get stuck in handling too much paper

Collaboration between departments	are responsible. He looks at this, and let's say for example the hole is too big, need to be tighter for the pin or something. Then if he says ok I agree, I will make the change, and then he writes a PCR, product change request. Then it goes out, and then it comes back to us. And we have to state what's the cost and consequence of this change for tooling. And we get this question, we send it to the Cixi plant, the Geely guys or the CMA guys, and we say here is a change, will probably affect your measuring tool or just the CMM program, can you give the cost and consequences for this. And we put it into the PCR. That's the very official way. We have this documented way of life cycle. The certain statue of releases, after one certain time, we must do everything in control.			
	It depends on where on the projects we are. In developing phase, we have normal engineering meetings or VJK meetings. Then it should be guys from	Need to have meetings whenever find problem areas		Official way: Normal engineering meetings with Stamping, Painting, Geometry, A shop and

Collaboration between departments	stamping, painting, geometry, A shop and design. Then we discuss changes, problems and we have to get concept together and so on. So there is a central meeting in developing phase. We meet once a week. There is an official meeting with standardized agenda. Then we go through every change we have done or should do, problems coming everywhere. Can be from crush, C, PK, PQ etc. A lot of things to compromising. And in this VJK, I don't know how to translate, it's ME feasibility approval or something meeting. They have this standardized list where all the parts in the project are and they have questions. A lot of work meetings depending on how the projects are. There are always some problem areas, where we will have meetings.			Design in developing phase once a week with standardized agenda.
	The most common problem is, R&D wants to have very small tolerances, and we say it cannot be feasible. We can't build the part they want. We don't get enough space in spot	Need to have meetings in every level to discuss disagreements and make compromises	Different departments have different requirements on the product	

Collaboration between departments	welding etc. Stamping has problems always. We have engineering meeting and discuss this can be done or must we move it. Then they must go to packaging and say we can't do that. We must have more space in package and so on. And it works and then packaging says, we have too big, this must be more space. Then we must create space. Where should we draw the line? In this case, there are lot of judgements, discussions, try to find previous projects similar to this. Then we try to talk to Volvo to discuss. So it is always a balance, a lot of discussions. I think usually we got high approve in Sweden; we can have good discussion say what we say without being angry because we have different goals. To build a car, huge compromise.			
	And also, very important for our area, attribute in ME, what car should be competed with us? Because should we be the best of best? The middle	To find what is the competitor		

Collaboration between departments	class car? But still, that also related to the cost. Because the more you asked, the cost would be higher. We can build a spaceship, but nobody would pay for it.			
	Tolerances: It depends on in which area we are and how to do it. So we started from single part, the sheet metal. We have standard general tolerances and that is what we started. Then the geometry management would build calculation model and calculate it and they would say ok with this tolerances we cannot have a car. Then we start to have discussion. Then we could say what is the more valuable for this car, and ok go for that one. But that is not so very often.	Depends on in which area and how to do it. Have meetings to discuss disagreements. To find what is the most valuable for this car and go for that.	Different opinions from different departments.	Start from general standard tolerances, then the DM would build model and calculate.
	It should have locating on the single part in the way we are holding it as we handling it. That is the main rule and we also have some exceptions. It should be a robust system so it's well defined. It is not one way to locate part. It is always compromise with	Need to find balance between PD and production.	Different needs in real production.	

Collaboration between departments	welding, welding spots, how we clamp it, and how much machining surface and so on, how is the datum. So we must consider the balance in between. We have different goals in this system. And all of these need to be compromise in the engineering meeting.			
	There are exceptions for different reasons. Some of the reasons might be, if we take windows for example, where should we put datum on that windscreen that has a ceiling that goes all the way around the big part in that way? We need to put out the datum in some areas. But in reality, it is basically all the way. So it would not be exactly the same.	Need to change according to the reality		
	The system engineers, it's we, it's PQ, it's manufacturing engineering and styling also, pretty much everyone, not purchasing and stuff like that. 4 or 5 departments involved if you say DM is 4.			4 departments are present in these cross-functional team meetings: DM (DE and PQ), ME, SE and Design.
	Of course communication can be better, absolutely, the communication		High workload can lead to communication	

Collaboration between departments	is very important, when you have high workload it's more important but then you forget maybe to communicate with someone else so of course it can be better.		problems.	
	If I go back a year or something between us and manufacturing, things was not that good, manufacturing had lack of people and we need to communicate but I think we're working on it every day I would say but it can always get better, exactly how it's hard to tell because I don't believe in meetings, be put in meetings it's more like face to face maybe let's go and talk to the guys.	Need more communication face to face.	Lack of people difficult communication.	
	It could be anything, it could be discussing the tolerance level, it could be how to build together assemblies, how to assembly a part on the assembly line, it could be a lot of things, we have different aspects. ...It's the system engineers who are responsible for the car but you can of course bring it to the project if it is very		Disagreements with ME can occur.	In case of not coming to an agreement with ME, SE is responsible for final decisions regarding the car.

	important.			
Collaboration between departments	How to solve it: I explain mine and they explain their side of it and then try to find.. A brainstorm to see if we can fulfill both of our requirements.			A brainstorming session can help to find a solution that satisfies all requirements when disagreements occur.
Collaboration with China	...during the builds were trying to have somebody from upper department in place during the whole build phase to cover problems that	To have key persons in the right place in China.		

Collaboration with China	can show up so we have someone in place that can see and report back to us...			
	In European companies I think normally you will have...the top manager is the one who has the final say but it would be a little bit more discussion, diplomatic perhaps you talk about things and it seems to me at perhaps because Mr. An is a bit far moved from where we are, he comes and makes a decision he is here for a short time, he hasn't have the time to listen to details just that is what you want and that is what you get.		Deal with cultural differences in structure organization. Distance makes more difficult to have the time to listen to details. Decisions are made from above.	
	We are in lead for the cars that we developed since we are responsible for the complete way, but we are not supposed to be in China and work on site except for supporting. We need to work very tight together and in the end; we are responsible for the car comes out as a good car. So we are in lead. So it is very difficult if there is any problem and solves it from here. Communication is	Support the team in China.	Communication problem (language) and cultural differences. Long distance makes solving problems in time hardly possible.	

Collaboration with China	problem. The simplest thing to get skype meeting with China is not always easy. Then we have communication that we speak English and Swedish as always, they speak Chinese and little bit English. This is very hard, and of course there is a cultural difference, how we express ourselves.			
	It is always difficult if it is on 2 different places to have the same way of working, of course there are language things, it could be misunderstandings and it takes time to understand what my counterparts, when they say something because maybe for me it sounds like oh he doesn't agree but maybe he did agree.	Need to improve the level of English and understanding of the Chinese and Swedish culture for each partner respectively.	Different ways of working. Language problems. Difficult to untangle (translate) the corporal expressions.	
	And of course culture things, how to manage a department or company I think it's different in Sweden and in China. It's the way of handle a boss, it's a little different, I've talked with the guys in Hangzhou about it and...But I think Sweden is a little different it's not like in China is different. I can say to my boss exactly what I think,		Cultural differences between China and Sweden can cause misunderstandings. Chinese hierarchical organization structure against Swedish more flat structure.	

Collaboration with China	it's no problem but they cannot do it in Germany And of course culture things, how to manage a department or company I think it's different in Sweden and in China.			
	In Sweden we are the front office and they are the back office so we hand over work for them to do. If I ask them to do some calculation so they do it and communicate with me and say if this is ok because they are quite new in our software RD&T and the way we work here so they communicate with me first and I say ok send it to the customer.	Improve capacitation on RD&T software as well as the way of working (according to Swedish working procedures) in Hangzhou.	Chinese are still learning the software and ways of working and need confirmation on their work.	Sweden as the front office handles work over to China like RD&T calculations, needs approval from Sweden.
Improvement potential	I see some possibilities to improve when it comes to the work together with ME press for example stamping, especially when we have selected one supplier we still need feedback I we have done a change then we need to know if this is feasible for stamping we send this for calculation to China department and they do a calculation and then	Simplify routines to save effort and money.	Unnecessary double work. Useless calculations.	

Improvement potential	after that they send this same information to the supplier which actually is the one that should produce the part and we have seen that we can get totally different answers and I see that this China calculation is worth nothing for us because we would like to send the parts directly to the supplier of course there we will have the correct answer from them and we will save a lot of time if we don't need to do their calculation first and I think it doesn't make sense to work in a way like this. Of course we can use their calculation before we have selected the supplier when we should try to do the parts as feasible as possible from the beginning but when we actually have the supplier on board the communication should go directly to the supplier, the tool maker, that's one thing I would like to improve.			
	There is a lot of improvements that can be done when it comes to systems we work with since they are started up from	Need to improve systems.	The company is quite new and the systems have not been fully developed yet.	

Improvement potential	more or less zero when we started up this company so that's an ongoing work to improve those systems and we have updates quite often in the systems to deal with these.			
	I don't know what is the issue with the China plant whether is a language issue or whether is the fact that we don't know who the responsible talking partner is but I think also it's the case of this is the first car we are building the CX and we are just in learning process that people at the moment don't know processes so it should improve for every car that we build.	Need to clarify responsibilities to avoid misunderstandings. Need to learn processes from own projects.	Lack of awareness on who bears the final responsibility. Lack of knowledge in processes.	
	There will be KPIs, because there are some stuff in the company. For example, one of these would be we suppose to run our PCR in time, that would probably be come. And there will also be some we deliver in time; I think there will be a lot of discussions there. We have not received any official one. They are now broke down from our CEO and down.	Need to have clear KPIs. Decided by CEOs and then broke down into every level. The whole company needs to be in the correct way.	Lack of specific KPIs to measure the performance and capabilities etc.	Small meetings every quarter of the year. Then half year review. And every year review.

Appendix B– Customer data template

Improvement potential	Every quarter we should decide it with manager, every quarter of the year. That is the small meeting, then we have a half year review, the big one is every year review. So it should be four times a year.			
	Yes, absolutely, more IT things I would say. We need to talk more, the best way is using the video, and skype meetings but the problem with skype meetings...it's not working in China. I cannot say what is the problem, when I try to skype with Chinese I hardly never get it to work	Need to improve IT tools for communication.	IT tools for communication with China do not work as well as they should.	
	I think so but we have differences, when we started up with the Hangzhou team they are used with the Geely way we had to explain we don't do the Geely way we do the Volvo way, CEVT do like this so they have to adapt to the way we do, because we can't have 2 different ways when we work. The guys who work with us have to adapt, I don't know really if there are other departments at Geely that work with the Geely car are	Need to adopt a way of working that is common for all CEVT and Geely employees.	Differences in the way of working at CEVT and Geely.	

Improvement potential	doing in another way I don't know. CEVT has to do it in CEVT way, Volvo can do it in Volvo way, Geely can do it in Geely way but it is important to do the same if you work for the same company.			
Information loss	I'll say it's the big flow of information, too much information, I mean sometimes people are sending out information and they are putting people on CC that doesn't really are involved in this just for information I would say half of all the mail you got is like just "for your information" and that would be too much information, and then sometimes something that is really important can be disappeared in this big flow.	Get relevant information.	Too much irrelevant information. Important information can be lose in the big flow.	
	It's only when perhaps people change departments or leave the company and get a new person come in and it's a new person taking around ….to be aware of, you get a couple of	Secure information storage when people are leaving a department and make sure new employees' contact information is spread to the right people.	Information loss can occur when people are changing departments or leaving the company. Takes some time to incorporate a new member to a team.	

Information loss	weeks of get confusing you send a mail and don't get any answer back or something like that.			
	It's happening too many things here too fast. So it's something for between to share so to say. So communication is a problem for us internally. We actually had a survey done and we went through it just yesterday for all the companies. And one of the red areas is communication between other departments. It is not working as well as we hoped but it should be. If you take how do we communication in production, we don't have a reproduction yet. That's an unwritten paper.	Need to improve communication between departments at the same rate as developing is happening.	Things are happening too fast and it's an issue to catch up on the development. Bad communication between departments is a problem.	
	It's probably communication for instance if system engineers they do some changes on their part and they didn't communicate it to us, could be that they took away a datum, that is not good but eventually we find out probably when we look at the cad data and we go back to them and yell at them. Maybe information from	Need for education about the importance of good communication between departments, especially regarding changes in the drawing, all changes must be informed.	Bad communication between SE and DM can lead to information loss; all important changes must be informed.	

Information loss	our side, we should probably inform better or have like education that they cannot change anything how they want, they cannot for instance cut a guiding pin or something like that because then affects everything. Education I think, the system engineers have to understand those things are holy things.			
Communication between departments	If we have different opinions of course we have to sit down together, a meeting to solve the problems.	Need to solve problems together through meetings.	Different opinions within the departments.	
	DE is mostly to get all the parts together and fit correctly together but if that is disturbing in some parts that will come after or it will be some disturbances to any important requirements that we have then we need to find the solution, there is not only one way to guide a part there is several,	Geometry assurance demands would not interfere with any other important requirements.	Disturbances with other requirements can occur.	

Appendix B– Customer data template

Communication between departments	there is always one that is suitable so we will always find the solution for this.			
	I know there are communication issues where people have lots of work; it's difficult for them always to find the time to prioritize my question...so we have to be flexible try to find time to sit face to face and have a meeting.	Need to meet in person to discuss problems.	High work load makes difficult to meet in person.	
	We have big integration meetings at packaging department they have a block leader and they have their own people responsible for different areas and it's my responsibility at styling and block leaders responsibility at the vehicle integration department to always filter out this information to the correct people.	It is the block leaders responsibility to filter out information to the right people.		Integration meetings between design and packaging department.
	IT. That is a big problem for us. All the systems are developing in half way and no one can log into everything. There is a lot of technical problems. But take RD&T for example that cannot communicate with TC, which is a big disadvantage for us.	Technical tools need to be developed.	RD&T cannot be opened from TC directly. Communication between different software should be more convenient	

Communication between departments	Normally it is very common if we communicate through link to TC so it can get the models by itself. And also, save in TC, and then the R&D engineer should be able to pick it up the data. ... That is double work, why do we do this? That can be with Catia, TC, RD&T, and it can probably be more. And save as 4D (?) should also be included some way. So don't communicate with each other. I think this area is underdeveloped. It should be possible to do quite more than that.			
Communication with China	We have CEVT Gothenburg and CEVT China and it happens that they are working a little bit on their own sometimes I have noticed and we don't get all the information that is needed, it has happened for example that they have started up a supplier to do a change for example quite costly change	Improve communication with China in order to avoid misunderstandings.	Working in different ways and lack of information leads China to take wrong decisions without approval.	

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Communication with China	also before we got management approval actually from this site.			
	They are really keen on to get the changes in as fast as possible because then of course would be cheaper, the sooner you do the changes the cheaper they would be so their intention is of course good but there is always a risk that management say ok we shouldn't do this change it's too expensive for example if you have started up with the supplier what would happen then I mean the supplier would have some payment for the changes done in the tools so that is a little bit dangerous...In general the Chinese guys they want to have the changes in as fast as possible and sometimes it goes a little too fast.	Need for better coordination with China in order to avoid unnecessary expenses.	Desire from China to implement changes as soon as possible can lead to expensive consequences.	
	The language can be a little bit tricky sometimes they need to improve English. There is a requirement from our site; we need some of the Chinese guys here to coordinate the work to China.	Improve language skills in English of Chinese employees.	Difficulties in communication due to different languages and level of language skills, both in Chinese and English.	
	There should always	Need of a window	Translators may not	

Communication with China	be a window person from the supplier that should have good skills in English but also have at least quite good technical knowledge about the things that we are discussing because sometimes when there have been some from like purchasing department they always speak good English of course and when they are coming and they are the translator and they don't have a clue of the technical issues and that is not good either even if they can translate back from the Chinese team but when we are asking them technical questions this person should translate it back and if they don't understand what we are really talking about.	person with good technical knowledge and not only language skills when having contact with suppliers.	have good technical knowledge.	
	I know there's been issues that they go there and sometimes the car that they're planning to look at has not been built yet, there was a delay and no one was told so you end up with the stylist travels to the factory and there's nothing there to look at so it's a waste of money, they come	Need to clarify the importance on communicating delays in production.	Miscommunication on delays at the factory. Waste of money in unnecessary trips to China due to communication issues.	

Communication with China	back and go back another day.			
	Just even if we want to, it is hard to make communication. I would say we have three main reasons. One is IT; it is hard to talk to each other. We can send mails but emails are not good. Another one is language, that's always a problem. Some Chinese don't speak English at all and some are very good at it. Then we have something that is something we don't really have anything to do about it that is time differences. Because if we should have a meeting with China, it should be 7-10 in the morning at Swedish time. Then they have to go home. 10 o'clock is always stretch, and 7 o'clock is also a stretch in Sweden. So for example we had a meeting started 7 o'clock today and ended at 9 o'clock, and still we felt that we need more time. Getting to know each other, face to face, that is very important, so we can have common understanding. So have the first meeting just to know each other, first	1. Get to have direct contact face to face in the beginning 2. Talk in the same language with smooth technical support	1. IT support. 2. Language problem 3. Time differences	

Communication with China	meeting, face to face, then you can explain everything. Then we can talk in the same language and technical things, and then it is much easier. There is also one thing that the IT should be better, because we have very nice screens, we have video cameras, and we have that park that we could connect to our computer if it works well. But you see it sometimes doesn't work.			
	I would say we are trying to learn it. There is a problem, because Sweden is quite, we take our own decision. But in China it is very common that the boss is invited to the discussion and raises the problem and makes it as a big thing of it. We have differences there and we have some areas that been clashing because we think that is a little bit rude to do that. But in China it is normal. I would say that is a problem because that stops the communication in a good term. Swedes prefer to have called and discussions one on one in a lot of cases but Chinese doesn't do that.		Cultural difference in organization structure and ways of working.	

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Communication with China	They send emails to half of the companies and explain what this is a very hurry thing.			
	It's good to communicate verbally but it's also good to write an email on what you have talked about and also it's good sometime to have a face to face meeting if it's possible for people from here to go to China so if you talk to the person in real life then is easier to continue with the communication and vice versa people from China come to Sweden too.	Verbal communication face to face between Swedish and Chinese is encouraged if it is possible to travel.	Distance between China and Sweden difficult communication face to face. Long trips are required.	
Capability	Specific rules to follow there is, we	To follow international		

Capability	have standards specially when it comes to location holes there are standard sizes...I would say is very general for other audiences as well because they are buying fixtures from many companies around the world and they work approximately the same way, so there are some standards to follow.	standards.		
	I think maybe 70% in-house. We only outsource the small ones. And if it is important to assemble maybe in geometry side, maybe we will keep it in-house, so we can control it.	Keep important part production in-house and only outsource small ones.		
	To measure it in production, it depends on where we are. If we have suppliers, we check the output quality of parts. We have a 50-50, 70-70 rule, kind of cpk then. We have a concept that worked quite well at Volvo and we have a standard that is visiting 70 views. Just go for 50-50 rule for collect measuring examples for some months. We start with the whole line and see if the whole line is ok. If there are	Use the rule from Volvo to measure the quality. Do analysis studies, what is called measuring checking feature.		Quality check and measure by picking samples.

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Capability	problems, we break down to the smaller points. ...But what we do is that we pick up some fixtures and ask them to measure to see what we can manage, as much as we can manage to see the fixture is capable before we start VP2 and see that is good. And we also have analysis studies also sort of capabilities, not real products but also see that measuring system is ok. That is easy and we call it measuring checking feature. But even we are now with the tool we don't check and say that is capable but we don't have measure in it. But we take measure attend 15 parts and say that seems ok, we don't have big deviation on it, we can handle it because we are not finished yet.			
	We take a part assembly and measure some holes and maybe some surfaces when we have clamps or when we locating things. That we measure 3-5 times one week for 5 weeks then we have a bunch of measuring data to check. If they are stable let's say it's ok.	Capability problems occur after 6 months.		Quality measure 3-5 times per week for 5 weeks to get measuring data.

Capability	We don’t usually have problems with capability when we started production. When it comes after 6 months, then it starts to be. The inline is 100% measuring, that could help us to understand that the line is statistically checking that it produces the same all the time. We do it in measuring and we want to measure more, but it is a capacity problem.			
	Subsystems for holding part, I would say we basically design by ourselves and make agreement with DM. If there is a problem we must say no.	Basically design by ME themselves and try to make agreements with DM.	High probably have disagreements with DM.	Design subsystems by ME.
	Geometrical variation vs. Realistic variation: One of the problems in simulation is that it’s too good. When you do it, it’s too easy to see the problem you focus. ... So in some cases it is easy to show something that is not that visible in reality. I don’t think that is the tool itself, it’s how to use the tool. Because it is very easy to show the problems, but is it that a big problem? On the other way, we also		1. Not realistic of visualization in real production 2. Not included every parameter in production. 3. Not consider process impacts.	

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Capability	have a lot of parameters that we don't simulate it at all in production line. So we are going to have big variation that calculated regarding to where gone all these forces. We have contacts from Volvo, the structure welding, we measure it before and after, we change it several millimeters. So the process has some impacts.			
	The process is more complex than the simulations are. We have people that put parts manually and we have ten people doing that. Is that in calculation? Probably not. You have gravity. Doors sag about 2 mms in reality for gravity, that's not in calculation, not even in CAE either calculated in a good way. We have door moldings. When you close the door, the A-pillar would push out for every car. Because the moldings need to be pushed out. How much could it be pushed out? The only way to know is by trying out. You can simulate it and get the value in this area it could be, but you will never get an	Need to be adjusted by the work experiences	1. A lot of process parameters not included in the simulation. 2. Manual work 3. Gravity 4. Matching is not as perfect as in Catia 5. Realistic variation differs every time	

Capability	exact value. So a lot of things we have weld spot. When we build something and simulate it, you have perfect matching in Catia like this, but in reality the surface would be like this. And it will be only be weld spot that put together. The weld spot is never 100% rigid, it moves a little bit. We have differences of coils. If coil has been standing in press for 2 months or one week will give different outcome. A lot of these are included in our tolerances and experiences say that we need to have this. But all of these process parameters and we have a lot of them cannot be included. Paint, I have seen it would move 1 centimeter during paint process, so it's extremely much and that gives us job. ... The process has a big impact of course.			
	We have PCF and TCP matching, that take cares a lot of the problems. We have the CMM measuring, that shows us what we moves and where we inside specification or out. If we are out, we need to do root	Solve problem as early as possible. PCF & TCP matching CMM measuring	1. Hard to find the root cause of the variation after beginning. 2. Everything we do in production gives variation. 3. New processes would bring new problems as well.	

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Capability	cause analysis and find out the problem. Then it is time I would say, to find the problems and solve it. In the beginning as we are right now, it is quite easy as problems are not big. So it is easy to find out what gives the problem. But in two years after this CS11, it is very hard to find what gives these variations because then the big one has been picked out. That is also about capability, is it easy to do it in a startup project or in a stall pre-adjust in a start production? But that's not the truth, that's what we have delivered. Then we see after things once a year; then we have rounded up and build a lot. And a lot of people have been in adjusted some spot things, problem program and so go and we start troubling. They have some variances that can be seen for process. Everything we do gives us variation. Hopefully it is a small one, but everything from press process, packaging, the part comes to coil that send to the A shop, that gives variation. To move it from the			

Capability	part to the line, clamp it, weld it, glue it, heating, everything will give us variations. That's part of challenges of this job also because we will always find new things that never stop. When we have new processes we will find new problems			
	It's not the ME department, the tolerance level should be handled...we should look at real values from the plant, measure data. We don't have that, that's the way it should be, we are using Volvo's measure data as far as possible in the beginning, and then in a new project if we have like a similar part we should look what have we used then and it's about the same if we don't have any major changes in material that could affect this one, but we set up the tolerance level in our department, we have to do the research what is feasible and then we put it in this GD&T documentation, which we need to agree with system engineers, with manufacturing and if	Need to collect real measure data from the plant in China when it becomes available.	Lack of real measure data from the plant in China for setting the tolerance level.	DM sets up the tolerance level. Volvo's measure data is being used.

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Capability	someone say I don’t believe in this then it’s important that we have done our research so we can bring up the facts.			
	I should look if we have any similar product in the previous project and look at the measure data for this one, then I should take that measure data and convert it to tolerances and put that on the drawing. That’s the way it should work and that is the way Volvo do. I’ve worked for 17 years in geometry and some other have worked longer than me, so we also have our knowledge about what the tolerances could be. It’s not the best way, but experience and also discussion, also you have to ask the supplier.	Need to collect data from older projects as well as experience and consensus with other stakeholders in order to set the tolerances.	Lack of own measure data forces the team to use Volvo's data and own experiences when deciding tolerances.	Measure data from older projects as well as experience and consensus with the different stakeholders is used to set the tolerances.
	We have a little problem there since we don’t have many measure data, but later on when we have measure data we should look at that and if we know that there is unpredicted variation we have seen then we should try somehow to implement it in the model it’s important.	Use collected previous data when available to predict variation.	Lack of measure data difficult to predict variation.	

Capability	You have a theoretical good way then you know what to aim for, maybe you might not get everything, you have to burg it, compromise. It's your experiences because you are responsible for an area not only a part, you can not only see for the part itself you have to see for the whole area, the lamp doesn't know how the bumper works therefore we need to be the one who see at the whole picture.	Have a holistic perspective (see the whole picture) when deciding reference systems. Need to compromise.	The theoretical good way is not always the best way.	Deciding reference system relays also on experience.
Flexset	It shouldn't be any effect for our daily work I would say.			Adopting Flexset would not affect the daily work of SE.
	We will gain especially to body because it is very common that we have 3-2-1 system. Little bit in calculation, but also in C shop for example let's take windscreen again. It's never a 3-2-1 system, it's always debates how should we do this, how should we calculate it, should we have two systems one for	Gain for body, calculation & C shop.	May have problem on measuring it and verifying it.	May solve debates on the positioning system calculation.

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Flexset	left hand one for right hand, in this case it will solve it. But I think it would be a big problem when we should measure it and verify this. We will have 3-2-1 system because in measuring machine, it can handle this. We have the best fit function, maybe that's the closest one, but I'm not so sure to use that one. There are also differences to understand it. Because you can understand 3-2-1 system, but that's also the only thing are going to do, also in that 3-2-1 system goes. We have other things are forced together. You assemble it, you just take these six points. Then we force, that's the process.			
	It probably would not save time in production, but maybe during evaluate point. If the car is better, yes it would save money. But how much money, ask after 10 years. Everything makes the prediction better saves money and time, but basically during launch phase I would say, not so much during running production. Because	No saving time in production but in evaluation phase. Save money but don't know how much.		Save time and money in launching phase, no effect in production

Flexset	the information we can get from this, is that we should maybe move locators, something like that. That shortened finishing run in production should be settled.			
	Maybe it can help us to find the best 3-2-1 system. ...Maybe it could give us better calculations; we have calculations that are closer to the truth. But still I think we would have problem, how should we measure it and how should we verify it, how should we understand it. ...It should be quite simple and clear and easy understanding. If we put two measurements on each other we should say be able in best of words, be able to calculate in what the final demands are and we check the final demands what have we said. When we start this flex systems, blows everything up little bit, makes it harder.	It should be simple and clear and easy understanding, gives better calculation and more realistic result.	Not clear how should it be measured and verified.	
	If it gets to work and the calculation is better, then we can predict the car better. ...It is always do better prediction do better for us also in the end, but we need to have this	Need to be easy to analyze.		It would help to make better predictions.

Flexset	easy way to be analyzed and it should be corresponding to that also.			
	I think it could be a good complement, the only thing that I’m afraid of when using the system is if you can bring out a lot of support points, it’s to start thinking, but in general it doesn't matter if you use flex or not because today you still need to understand and analyze the contributed list that get out, and understand why it is a contributor here and I think that is the hardest thing to understand.	Need to understand the results from the contribution list.	Worried about using too many support points.	Can be used as a good complement.
	Like it is today, your way of flex system is more complicated than that it is today so I prefer alternative assemblies if I compare how Flexset looks like today. You have to specify sets and then I want a point to use a specific set then I have to give the point to that set and if I understood correctly you don’t have to do that or? ..I think you could get a strange effect, that’s my	Need to show the advantages of using Flexset system.	Pre-conceptions about Flexset system like being more difficult than alternative assemblies or giving strange effects.	

Flexset	experience.			
	I don't know, the thing is if you implement a new tool in the software not everyone uses it. Right now we have the tool RD&T you should have the skills so you can choose what you like what is best you know the model there is 1000 ways to do it, as long as you don't do wrong things. In which area could be useful: Bumper could be good and also for body in white for instance the side panel.		Risk that people choose not to use Flexset and continue using the RD&T tool in the same way they do today.	
Production	Quality inspection: Geometrical output. There is a measuring machine or manual measurement. The target is the piss	Measure certain capability points on everything needed.	In-line machine measurement in Sweden but not in China.	Measuring machine or manual measurements.

Production	point in side tolerance. They have indirect measurement I would say, see how many people they need to adjust the door, something like that. But to measure values, it's CMA machines and fixtures. That is a good question because we have in-line machines; I don't think we have in line machines also in China plant. We got measurement in everything almost, certain capability points on everything we need.			
	After final assembly, that is measurement for process. Then we also have the subsystem, that we must go off-line measurements. Then it's CMM measurements. For me the subassemblies, also are more to check in process to keep up the checking issue the welding fixtures, so don't have movements on them. I think measure, probably three weeks. Of course it depends on the production rate also. For geometrical part, we do measurement on every single part. But we have	Off-line measurements in subsystem. CMM measurements as well. Check in process for the subassemblies. Measure every single part in geometrical aspect. Measure every single part in press.		Define measure steps and levels in PKRV.

Production	capability points, locators for sides like that, we measure on every car. Then you have other quality just tear down activities, to check weld spots and so on. How often I don't know, once a year once a half year. This is not very often. But also we measure single parts on press for example, that's normally measure in press set. So we see this press run was ok. I think 5 parts is normal. Then we have decided in the PKRV different levels of in-house to measure. So we don't measure every bill that we have. So if we take one part in here and one together with another, it is not sure if we measure that one. But we maybe build three or four steps more then we measure it. That's defined in PKRV as in-house subassemblies, which levels are measured. So I think for upper body 4 to 6, lower body maybe 10 to 12 in that area. And body in white of course, the hang on part.			
	Hang on part is probably the most common one, that's	Adjustments in A shop and C shop, depends on what	Hang on part is the most common one with the quality	

Production	the hardest one. That one they are checked in C shop also. So door holder takes a XXX, that's always the hardest. And especially we don't have a robust system. Then it means the adjustments in A shop and C shop. And we would say all produced car do that in different levels depend on what quality they want and how weld succeed it. All of them adjust something.	quality requirement is for every specific car.	problem.	
	We have geometrical maintenance. That means every six months, we go through the welding fixtures, clean it up and check for damages, wear off pins and so on, make changes of that. And once a year, we measure them. That's the geometrical maintenance. Then we also have maintenance on measurement machines and so on, measuring equipment. Then the measuring people also check the line in general more common, and go with the standardized way of working. I'm not	Time-based preventive maintenance	May not have access to do the maintenance if the production is full-time running	Time-based preventive maintenance

Production	sure how Volvo do it but on other companies they have this, every two weeks we should look at pins that they don't fall out, every five weeks we should look at well done and the clamping function. They of course have a long list because they check everything. But one problem is that, this is one thing that we want to do, but the second one is to have access to the line and do it. If we take Volvo for example, they have been doing quite well. They are running 24 hours per day and a lot of weekends, then maintenance of course, cannot be done. Because it takes a lot of time doing it.			
Deliver on time	I would say always deliver on time from body upper department because we need to we have to, it can of course some effect on the quality of the parts in that sense because sometimes we can see that we are not really finished and there is some problems that we	Solve all problems before delivering.	Rushing around to deliver on time can affect the quality of the parts.	

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Deliver on time	haven't solve but we need to release something...			
	There is so many pieces and calculations that has been done on our part that we are releasing to manage to follow the time, it's more important that we always follow the time plan from body, other things...can always been put there later on...but the body needs to be there first otherwise it doesn't work so I would say the most important pieces are under body and upper body, that we deliver on time is the base for everything.	Important to follow the time plan for body in white.		Body in white has to be released on time.
	There can be other reasons for delays sometimes, it can be that we are working with 2 projects at the same time they are not being in the same phase...we cannot release at the same time we don't have that capacity, so that would also be a reason for delays one project late and we have an effect on the next project also.	Increase capacity in order to deliver several projects on time.	Not enough capacity when people are working in 2 projects simultaneously. Delay in one project would cause delays in the other one.	
	There would be good if everybody understood that there is a time plan to follow...these delays can be avoided by	Need to clarify people's responsibilities and importance of teamwork and achieving common	Difficult to get all people to follow the time plan. Difficulties on getting people to see the big picture and	

Deliver on time	people just trying to see the end rather of what they want at the moment, anything from managers not making the right decisions at the right time or just make changes because they just feel that they want to put an input into the project and there is people not understanding their roles entirely and delivering the wrong information.	goals.	understand their responsibilities.	
	No not always, some TI is regularly late it depends on which department it is usually, some departments as I said are not so experienced with this way of working, other departments as body in white department have worked like this before so they understand, they work they deliver and everything rolls nicely. When it's delayed two things can happen if we don't see a way of making up the time then the studying delivery is delayed and in worst case that means the time plan goes... but normally we try to make some attempt to work a bit harder and get it done so we can cross the time	Improve efficiency in the way of working in some departments in order to be able to deliver on time and not affect other departments.	Lack of experience in ways of working in some departments can result in delay of deliveries which derives in increasing the time pressure and workload in other departments	

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Deliver on time	plan back to how it is or it was before so it is tough when something doesn't get delivered in time.			
	There is always some delay. To start production is the main goal, and then we have some scales of course. Then we have checkpoints, to check progress is going on the right direction. That of course we have. But that should be something very big to move to production. Then we must be ready there. I have never been in a project that has been well on time in every area. Now as a new company, maybe we are a little bit on the other side too much to gain, but I think that is normal in new company to get everything up and running. The first project we are running has not have finished yet. But I think that is common problem in all the projects that you are not always 100% and you will have some problems about running production and starting up production.	Need to follow the check points.	Not always in time and have problems in catching up the check points	

Deliver on time	It’s never on time. The main reason is that we have grown so fast as a company, so many people and we didn’t have an structure and it’s not easy to start but if I compare, go back one year it’s better today than one year ago and I think we will be better in one year from now, with the timing and everything, we have three programs...CX11 is not on time anything.	Need for learning from current projects in other to improve methods and timing for future projects.	The time plan is never on time. The company is growing very fast and there are not common structures.	
	For us maybe you don’t work through the concept or something and that delays the drawings and that would delay the start of tooling and it could be that you have to do some tooling changes, it could be more expensive, the later changes the more expensive it could be so it would cost more I would say.	Need to keep the time plan and avoid delays that could affect other areas.	Delay in one area would cause delays in other areas. It could cause the project becoming more expensive.	

Environmental sustainability	We of course are trying to create the body in white that should have as low weight as possible, I mean when it comes to calculations that is a very important thing of course but we don't overdo things because if a sheet metal part needs to be like 1.5 thickness and let's say that that one fails then we just go one tens over mil for next one and try again instead of actually let's do 2.0 because then we know that that will work but if it works with 1.6 we should keep it that way because the lighter the car actually is that will have an effect on the fuel consumption of course, so that is something that we work a lot with in our department keep the body as low weight as possible. If it is ok for the safety and the requirements that we have not overdo it we keep on the limit.	To keep the weight of the body in white as low as possible to reduce fuel consumption without affecting safety.		
	We're always working with trying to find different materials and hot forming parts for example is one big player in this, when we heat some parts up they will be very	Find better materials and processes without increasing the weight.		

Environmental sustainability	strong parts, you keep the same weight but they will stand the collisions better for example.			
	We have obviously a company policy to what's in the environment and there are intended to the vehicle itself... ...the material choices is another department it's cutter and trim that choose that and I don't know what they take into consideration for the environment there, the actual design itself, the form, the styling form it's not so much you can affect, I think it's mostly to do with materials and the actual technical way of producing the car that's more to do with CEVT I think.	Deal with material choices and manufacturing procedures to diminish the impact on the environment.		Company policy regarding environmental issues.
	I think what you have to take into consideration is weight of the car all the time, you save weight then you save on pollution and that is something that design can affect, the aerodynamic aspect of the car and the fuel economy, this is something that of course an aspect that designers consider as well as try to make it look	Besides styling designers have to take into consideration weight and aerodynamic aspects that could affect fuel consumption. Keep fuel consumption as low as possible.		

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Environmental sustainability	nice, I think that is still the primary wish for the design but they consider other aspects of course.			
	I still don't think the car industry as a whole is fully focused on producing environmentally friendly vehicles.		Producing environmental friendly vehicles is still not a priority.	
	Those things I don't think about, I frankly don't know who is responsible for those things.	Need for more awareness about environmental sustainability matters.	Lack of awareness regarding environmental sustainability matters. Unawareness about who is responsible for that area.	
Social sustainability	ME they have quite tough requirements for example we should have any sharp edges in the sheet metal parts it's better to do round corners, there is always requirements like this, when it comes to how to mount part you will try to avoid the under up mounting for example it's not always possible but as far as possible we will try to avoid this kind of operations.	Requirements for good ergonomics for the car's users and the workers at the factory.		

Social sustainability	Pedestrian protection, we have to consider that when we design the vehicle so that's all part of the technical input that help the designers with, but in terms of the ergonomics of the workers in the factory that's definitely manufacturing department here at CEVT.	Take into consideration pedestrian protection in the design.		ME takes care of ergonomic aspects at the factory.
	Yes but we are not sure how it is in geometry side. We don't have any vision about this. It is important for the company and it takes care of production people. They have a lot of things of course; especially they have glue things like that. That is too far from geometry.	Take care of production people.		No consider in geometrical aspects but yes in social aspects for the production people.
	Here we have cultural differences. From Volvo part of view, we have a lot of rules for glasses, shoes, clothing etc. That is also small differences between A shop and C shop. We have very aggressive environment in A shop with platters, sharp edges on panels and so on. I think they dealt with it. They reduced quite a lot injuries	Need to have more specific regulations in China about ergonomic issues.	Unbalanced development in social sustainability between Sweden and China.	

Social sustainability	but it always happens. Noise is regulated, almost removed from 30 years ago. Now we have earphones in production, which is not a necessary thing that we used to have. Also we have ergonomics, it's more controlled now. How does worker stand could influence the weight they are holding and it's more regulated. If you work up and down, there are a lot of regulations, I am not an expert on it but everything is measured. It is a very important parameter when design fixtures. I'm struggling from it because I don't like it. I want to have robots working in stations. We shouldn't have people in the stations. Here we see differences between Volvo and China. Because we have asked China don't we have any regulation, and the regulation is to have a hard hat. I think it's coming in China but it's not in the same level yet. The specific rule would come later, I am sure for that. In the end the company is about people, at least we can take care of			

Social sustainability	our people. The very building should be the Volvo rules. Also you see the awareness of safety is very different. Chinese are not as awareness as in Europe. For 20 years ago we want to aware here either. We talked to our boss, I think it was 73 in the press shop, people have these two hand panels, weight on one of them and just push them into one panel and stand like this one press is going. This would not happen today, if someone does it, it would probably be fired. But at that time it's normal. There are a lot of improvements could be done.			
	We have an ergonomic department, should be under vehicle integration I think, my boss' boss. I guess there must be one, but that's environment for the car not for my work place.		Very little awareness about social sustainability.	Ergonomic department under vehicle integration (need confirmation).

Appendix B– Customer data template

APPENDIX C – INSTRUCTION OF FLEXSET FUNCTIONALITY

Flex Functionality

Flex is a new positioning system method. Instead of normal orthogonal and non-orthogonal positioning systems, Flex system could involve several points in just one positioning system while normal system could only have 6. It enables users to test different locating schemes easily both in conducting and visualizing. The purpose of this new functionality is to achieve the most realistic result in measuring points and more user-friendly and convenient than the alternative assemblies.

This functionality could be found in positioning system window within Edit Part window.

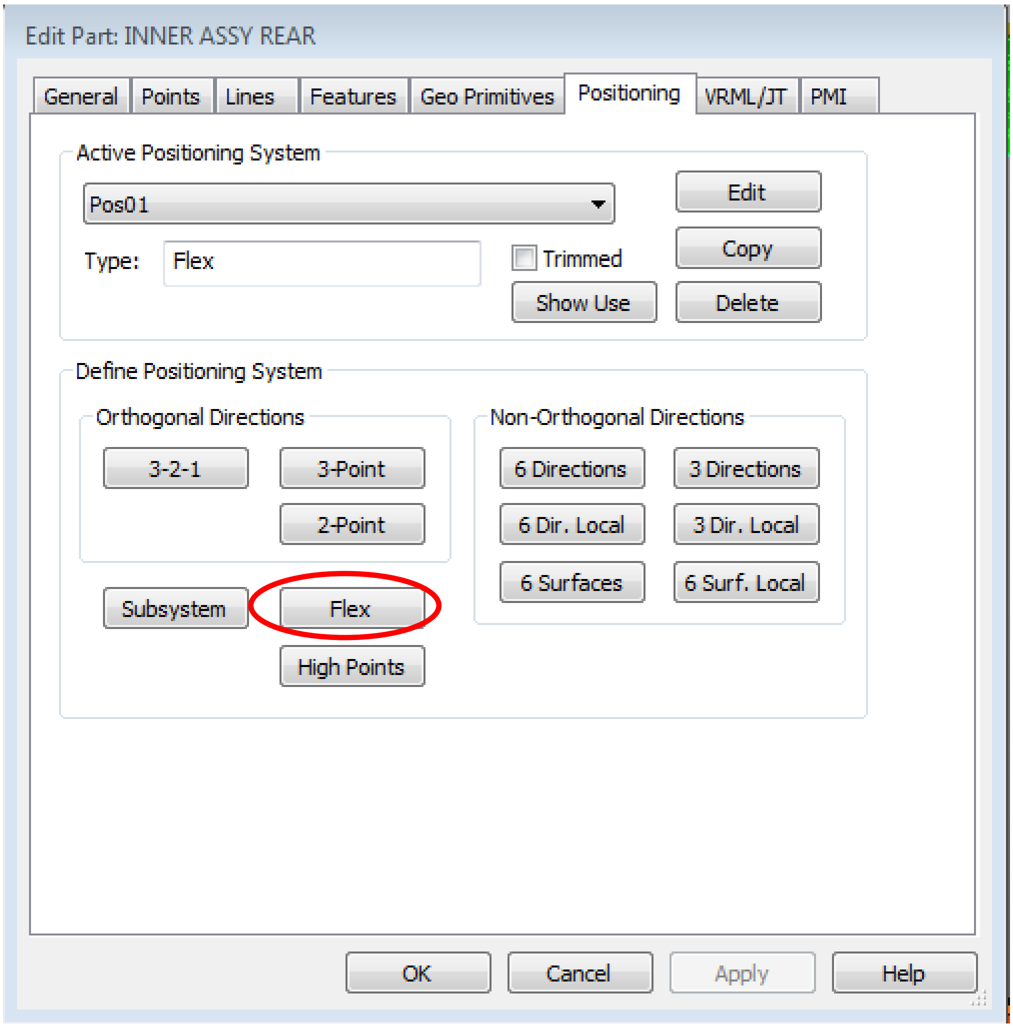

Figure 1: Edit Flex positioning system

Appendix C– Instruction of Flexset functionality

The common routine of Flex functionality is listed below

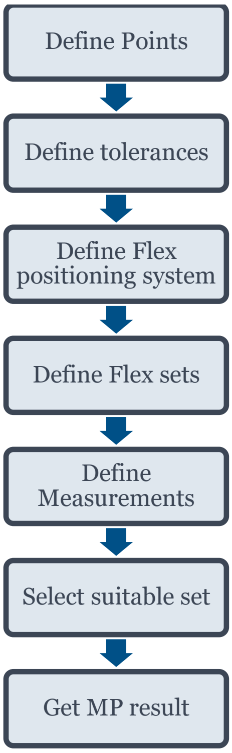

Figure 2: Process in Flex functionality

Define points

In Flex functionality, it is possible to have the 6 main locating points and all the support points that would be used in Flex in just one positioning system. It is suggested that all the points that would be used in Flex are defined by users in the beginning of modelling. Points could also be added in defining Flex positioning system if needed.

Defining points in Flex is the same as defining points in normal positioning system. Points could be defined in ¨Edit Part¨ for each part.

Define tolerances

For each point that has been defined in part level, it is important to give tolerance to each. RD&T needs specified tolerances in specified points to run Monte-Carlo based simulation. The tolerance defining is the same process as in normal positioning system.

To make the position of model more precise, different kinds of tolerances in each part and each level of subassemblies should also be defined. Tolerance defining is based on the real requirements of the positioning and users as in the normal working way.

Define Flex positioning system

In one Flex positioning system, unlimited number of points in local part could be defined in three directions for each part or each sub-assembly. Points could be added by button ¨Add A/B/C¨ and be removed by ¨Remove A/B/C¨ as well. A, B and C represent three different directions in the model. Then target part for each point could be chosen. Target points could be defined by using ¨Copy Local¨

function or using defined points in target part. If user only needs to copy a specific point from local to target, then ¨Cp A/B/C¨ button could be used. If requested, users could add new points on the local or target part by ¨New¨ button.

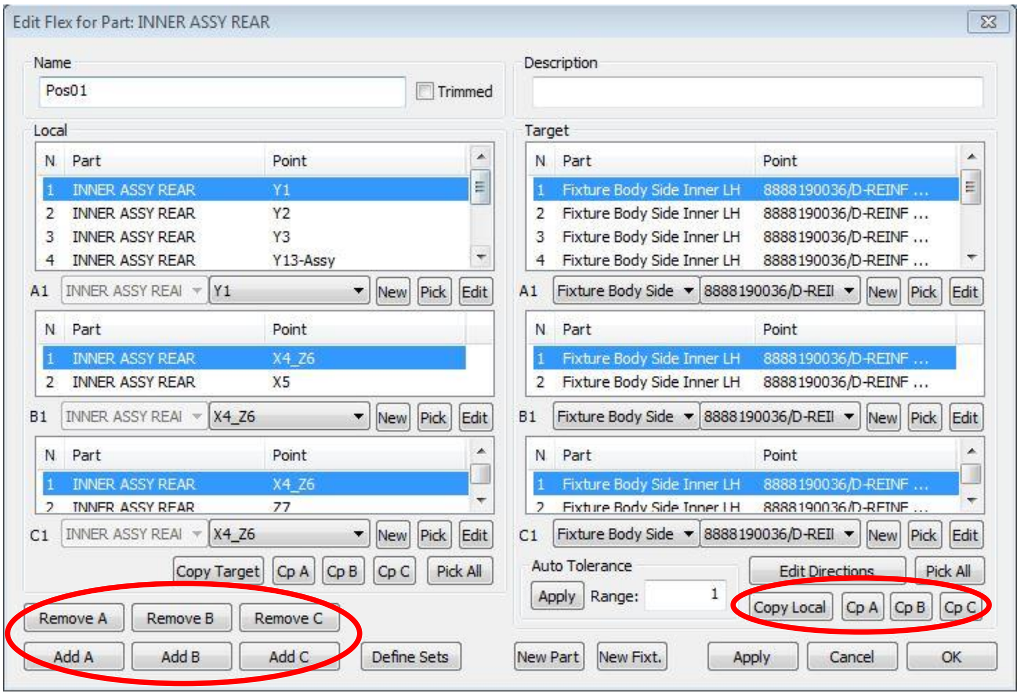

Figure 3: Edit points in Flex positioning system

To ensure the direction of each point, it is important to go into ¨Edit Directions¨ and choose desired directions for A, B and C according to the requirements. Click on ¨Apply to all¨ to apply would be useful when there are several points defined in the same direction. If the point is not in the orthogonal coordination, ¨Pick Cp¨ could be used to define a specific direction for each point.

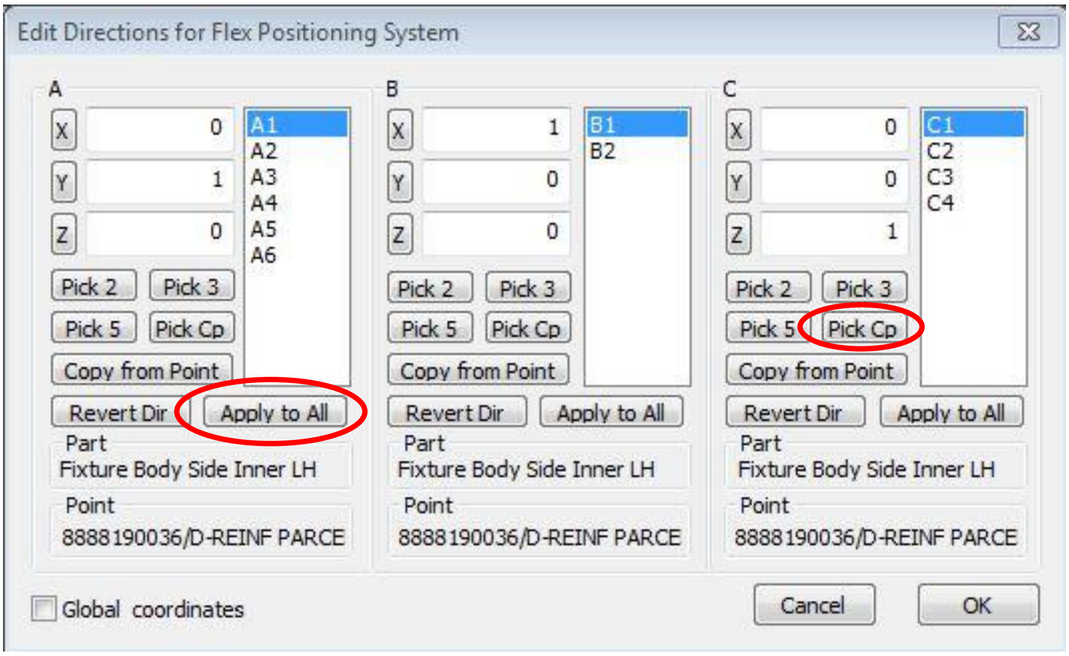

Figure 4: Edit directions for Flex

Define Flex sets

In Flex functionality, instead of alternative assemblies, there would be several sets at the same time within one Flex positioning system for each part or each subassembly. It is realized by ¨Define Sets¨ button in Edit Flex.

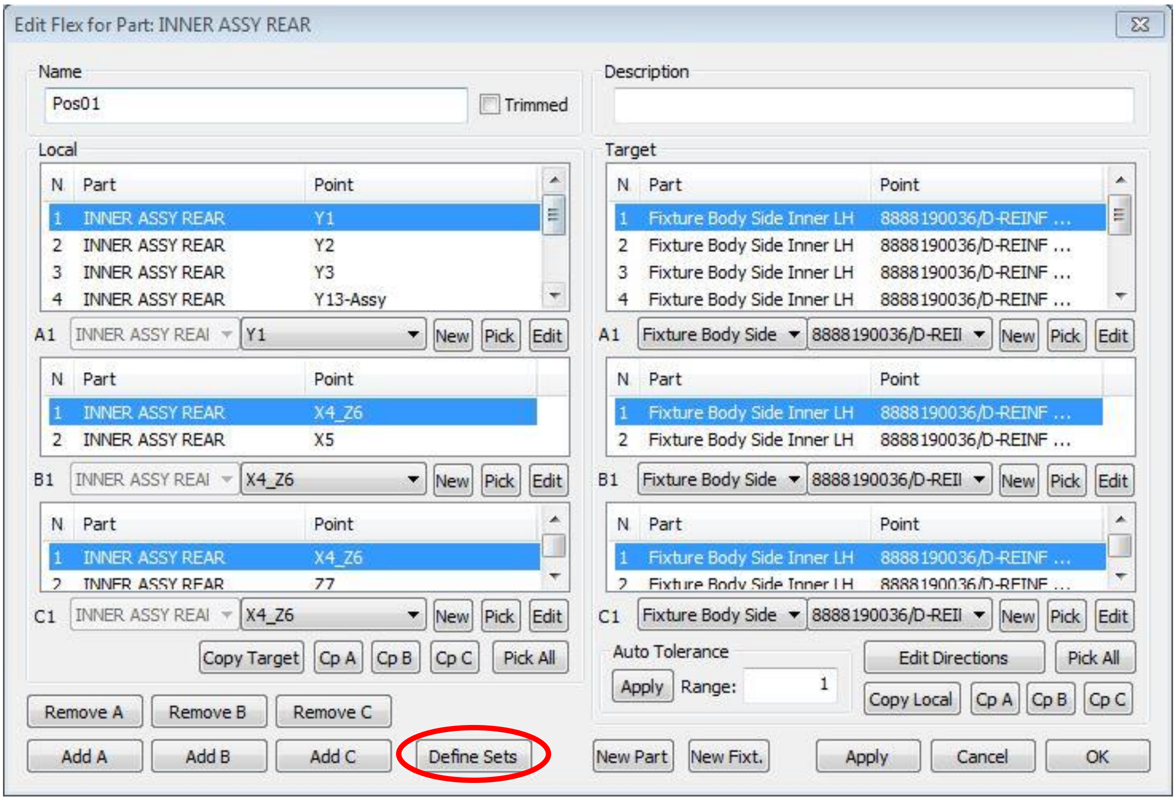

Figure 5: Define sets in Flex positioning system

Each set uses 6 points, following the ¨3-2-1¨ principle. All the points could be selected by defined points in each part. To have different sets, click on ¨Add Set¨ or select ¨Create All¨ in this window. ¨Create All¨ button would create all possible sets by all the defined points. (Notice: This button would create too many sets over real needs when there are a lot of support points in the part. Be careful of using it!) By ¨Add Set¨, user could select 3 points in all of the A points that have been defined, and two points in B, one point in C as well. A small cross would appear in the model when each point is selected to give visible support for users to check. All the points need to be defined in advance in order to be chosen.

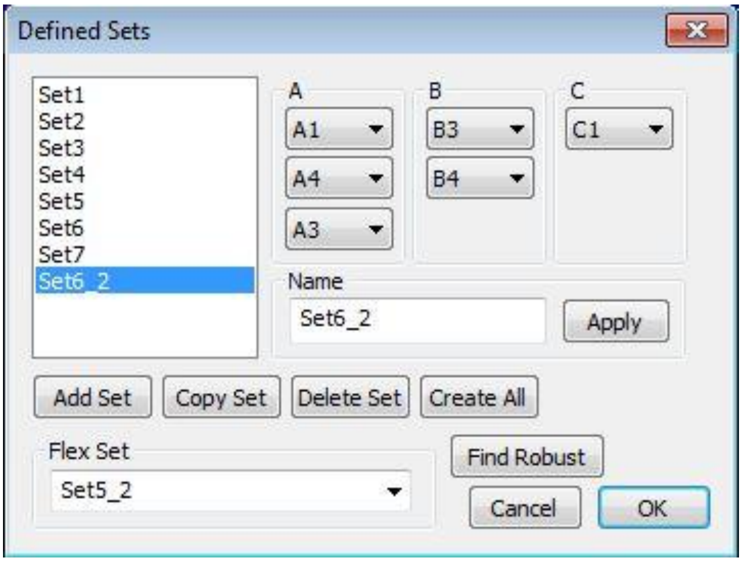

Figure 6: Defined Sets window

After a set is defined, a triangle would appear in the model displaying all the six points by clicking the name of set. It could help user to check the set immediately to avoid human error and very visible.

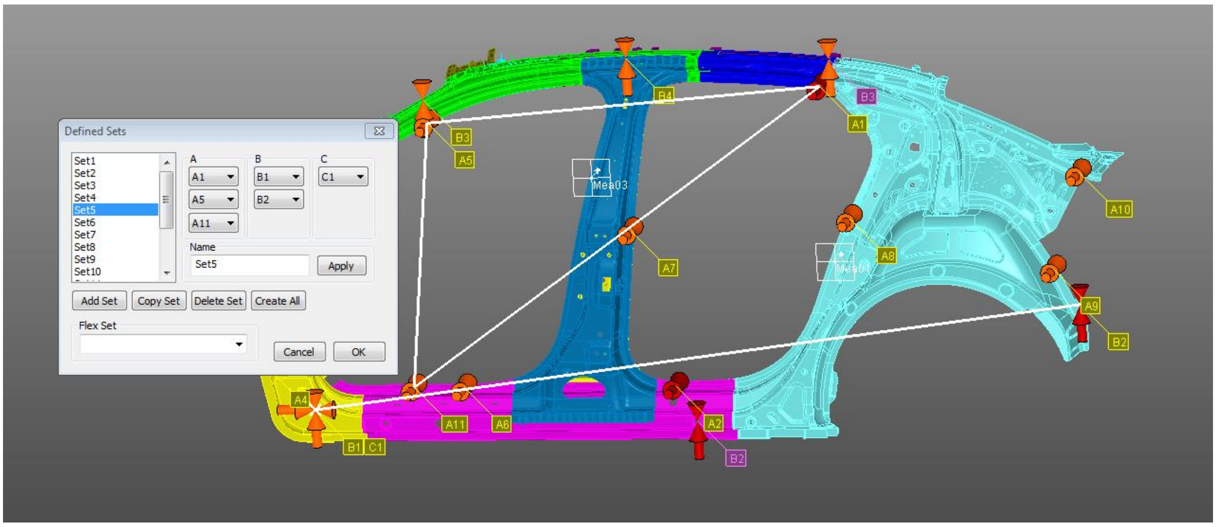

Figure 7: Visualization of Flex

Flex view

Flex sets could be checked in the Flex view, which is a new view window within VRML view window. It could be selected from the corresponding icon. Different Flex chains are displayed in this view as well. It is easy for user to check how the Flex chain looks like and detect the interrelation between each level.

All the subassembly levels and parts can be viewed in this window, as well as measurement points and related points on the part. Each set in each level, as well as default, is marked with a green circle.

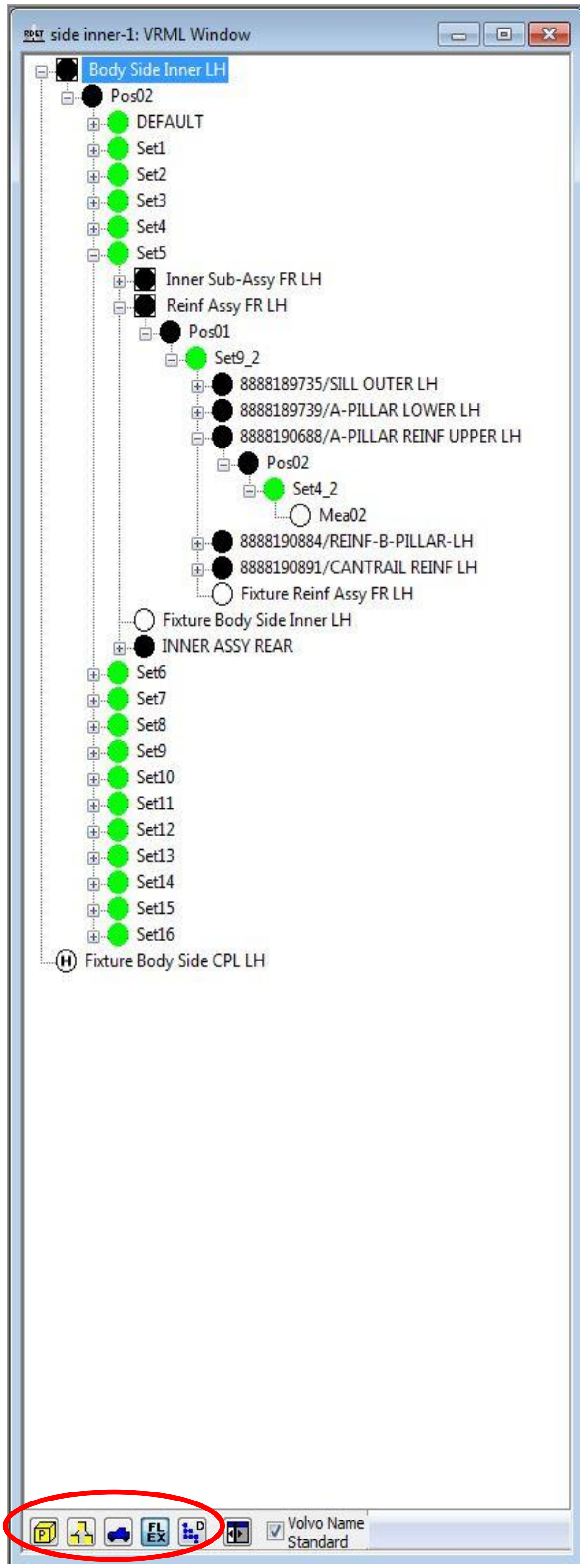

Figure 8: Flex view window

The convenience of Flex view can be seen from visualization. When the user click on the name of different set, a triangle that displaying the three points in A from this set would be shown in the model view, as well as a line indicating two B points and a cross for C point.

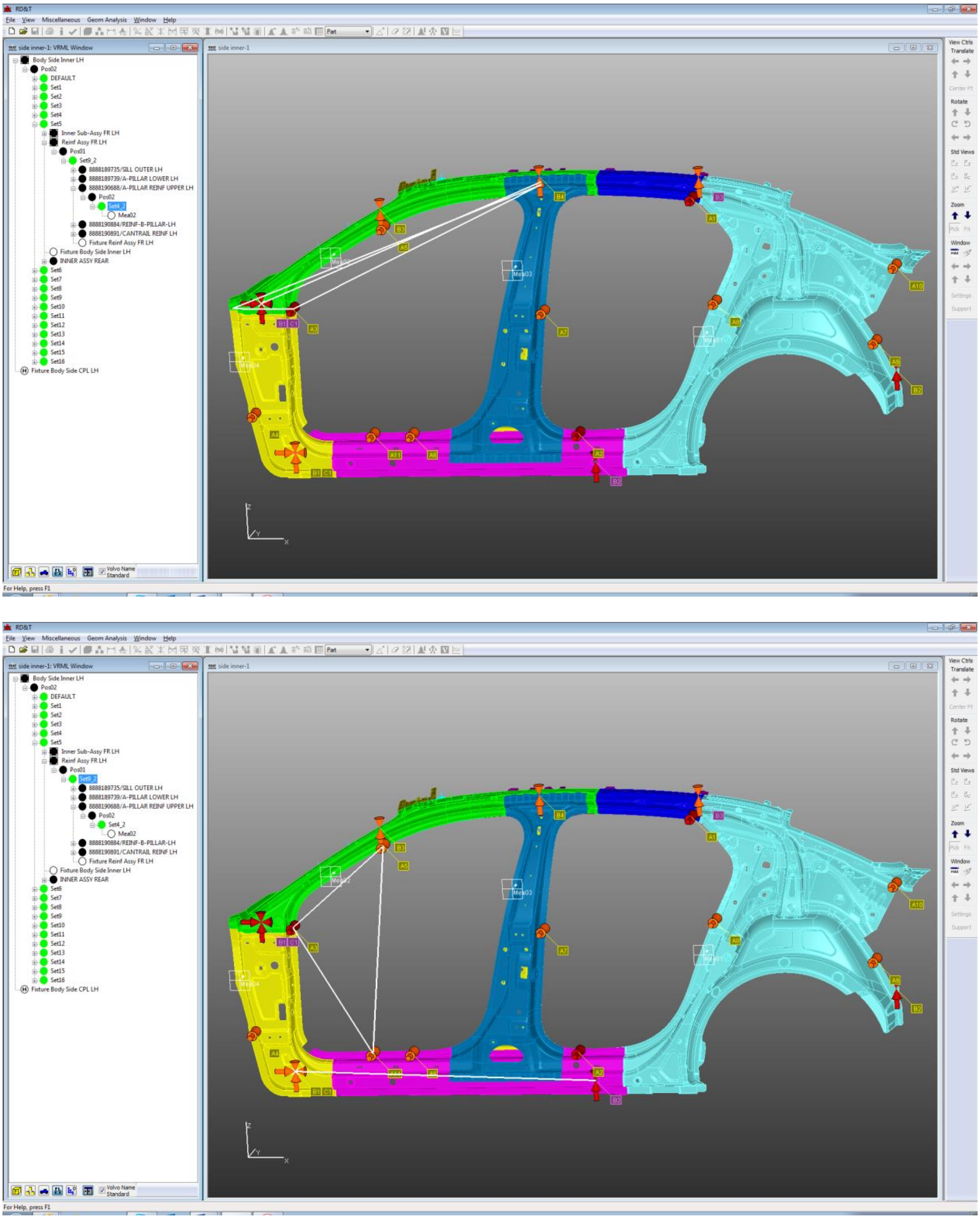

Figure 9: Visualization of different subassemblies

Define measurements

Flex functionality shows its value in getting more realistic variation analysis results for specific measurements, especially with several support points. When a measurement point is defined in a position that has a comparative long distance from its mass center to the main locating points but closer to specific support points, Flex enables user to choose the most suitable locating scheme for this measurement both automatically calculated by program and manually defined. Measurement defining is the same as normal use.

Select suitable sets

In Flex functionality, RD&T could select the most suitable set in each level and create a new flex chain automatically for a specific measurement. To realize it, user should go into the related measuring point, and select ¨Find Suitable¨ in Edit Point window as what could be seen in Figure 10. Then the calculated suggestion by RD&T would automatically appear in Flex Set in this edit point window, accompany with a new Flex chain in Flex view window.

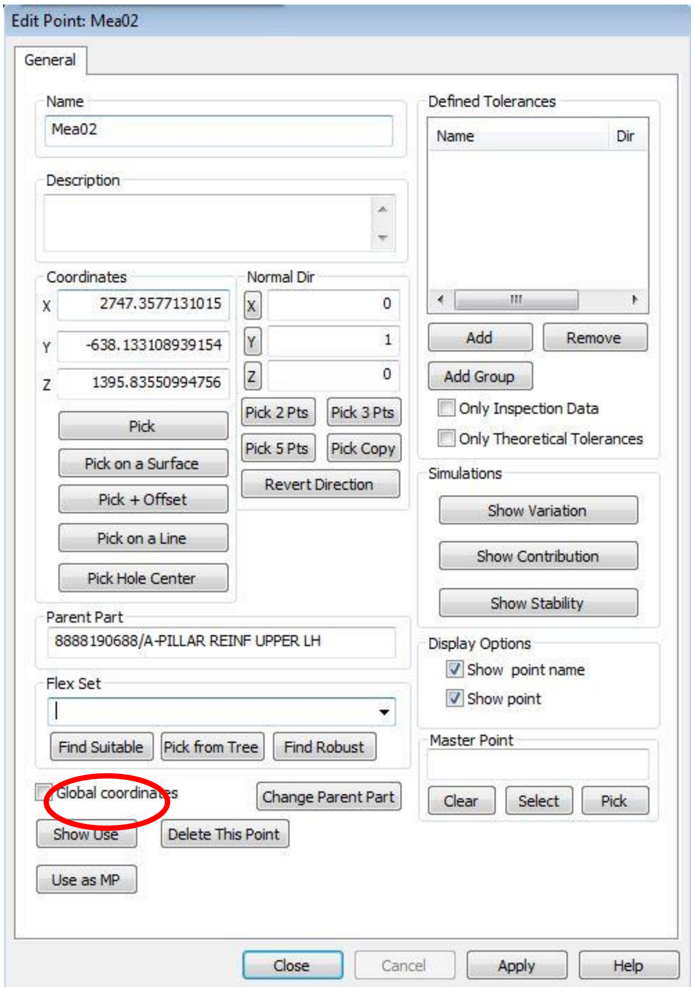

Figure 10: Find Suitable function in Measurements

User could also select a specific set manually from the drop-down menu in Flex Set if needed. In this way, the related Flex chain needs to be defined manually as well. For the selected set, user could go into the Define Sets window in the positioning system of this part or subassembly and select the chosen set in one level higher. This operation needs to be repeated in every sub-assembly level if user chose to do it manually.

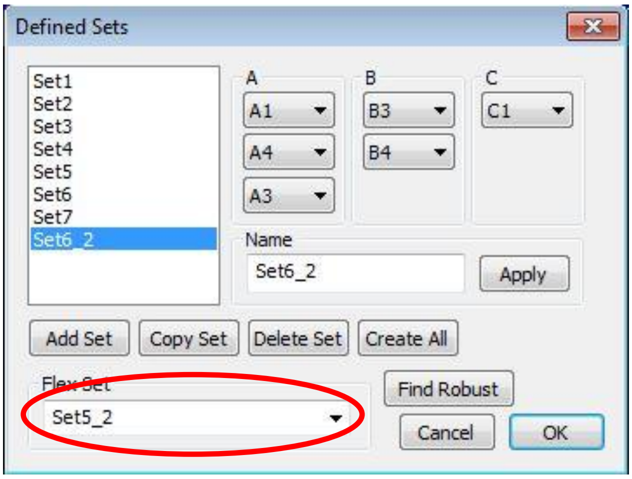

Figure 11: Manually choose set

Each set could only be related to one specific set in one level higher. If the calculation relates two sets in the same level to the same set in one level higher, the target set in higher level would be copied automatically in order to be related to different sets by ¨Find Suitable¨ function. If users define the flex chain manually, it needs to be noticed that target set could only be related to one set in lower level. ¨Copy Set¨ button could be used to avoid problem. It would copy the selected set with the same locating points and enable users to connect the copied set to another set in lower or higher level.

¨Find Suitable¨ in Flex functionality supposed to suggest the most realistic locating scheme in the model, which would be compared with the real production measuring data in the future.

Get MP results

Flex functionality could be used to get variation and contribution simulation results in rigid model as the same way as how it works in the 6-directions modelling, according to the requirements of users. The simulation results are considered as in the most realistic locating scheme, which would be verified in the future.