Utilizing the generic design analysis (GDA) process model within an extended set of design analysis contexts

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UTILIZING THE GENERIC DESIGN ANALYSIS (GDA) PROCESS MODEL WITHIN AN EXTENDED SET OF DESIGN ANALYSIS CONTEXTS

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ABSTRACT

In most industrial product development projects, computer-based design analysis, or simply design analysis, is frequently utilized. Several design analysis process models exist in the literature for the planning, execution and follow-up of such design analysis tasks. Most of these process models deal explicitly with design analysis tasks within two specific contexts: the context of design evaluation, and the context of design optimization. There are, however, several more contexts within which design analysis tasks are executed. Originating from industrial practice, four contexts were found to represent a significant part of all design analysis tasks in industry. These are:

1. Explorative analysis, aiming at the determination of important design parameters associated with an existing or predefined design solution (of which design optimization is a part).
2. Evaluation, aiming at giving quantitative information on specific design parameters in support of further design decisions.
3. Physical testing, aiming at validating design analysis models through physical testing, that is, determining the degree to which models are accurate representations of the real world from the perspective of the intended uses of the models.
4. Method development, that is the development, verification and validation of specific guidelines, procedures or templates for the design analyst and/or the engineering designer to follow when performing a design analysis task.

A design analysis process model needs to be able to deal with at least these four. In this work, a process model named the generic design analysis (GDA) process model, is applied to these four contexts. The principles for the adaptation of the GDA process model to different contexts are described. The use of the GDA process model in these contexts is exemplified with industrial cases: explorative analysis of design parameters of a bumper beam system, the final physical acceptance tests of a device transportation system (collision test, drop test, vibration test), and the method development of a template for analyzing a valve in a combustion engine. The "Evaluation" context is not exemplified as it is the most common one in industry.

The GDA process model has been successfully used for the four contexts. Using the adaptation principles and industrial cases, the adaptation of the GDA process model to additional contexts is also possible.

INTRODUCTION

Nowadays, many industrial development projects utilize computer-based design analysis. Computer-based design analysis (or design analysis for short) is here confined to

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quantitative analyses, utilizing advanced, computer-intensive computational methods and tools focusing on analyses of the physical phenomena which originate from the design and development of new or improved products or from the redesign of existing ones. Several works in the literature present process models to plan, execute and follow up design analysis tasks, and support the practitioner's work, e.g. [1-6]. NAFEMS (originally the National Agency for Finite Element Methods and Standards) has proposed several models during the last few decades that are intended for practical implementation in industrial practice [7-9].

Most of these process models deal explicitly with design analysis tasks within two specific contexts. All of them deal with tasks performed within the context of design evaluation, that is using design analysis to give quantitative information on specific design parameters, which are utilized in the decisions on the further design of the product-to-be. And some of them deal with design analysis tasks within the context of design optimization, e.g. [10].

During interviews in an industry survey [11] involving the heads of the design analysis and/or engineering design departments of 15 technology-intensive Swedish companies, ranging from SMEs to large companies, in which design analysis was of major interest, it was found that a significant number of design analysis tasks took place within a larger number of contexts. Four of those contexts were found to represent a significant part of all design analysis tasks originating in industrial practice. The identified contexts are:

1. Explorative analysis (of which design optimization is a part)
2. Evaluation
3. Physical testing
4. Method development

A rough estimate made by the authors, based on the findings obtained during the interviews, on their own experience as well as on design analyses referred to in the literature [11;12], indicates that these represent 65 – 75 % of all design analysis tasks. These different contexts have common but also specific design analysis activities and it is important that design analysis process models should be able to encompass these contexts.

In this work, such a process model, denoted the generic design analysis (GDA) process model [13], has been applied to those four contexts.

This paper is organized as follows. In a first section, the GDA process model is introduced. Then a second section explains how the GDA process model can be adapted to these different contexts. A third section elaborates on the four contexts. Finally, three examples from industrial projects show how the GDA process model may be used to handle the different contexts (the "Evaluation" context is not exemplified as it is the most common context).

THE GENERIC DESIGN ANALYSIS (GDA) PROCESS MODEL

The GDA process model has been developed from several sources: an extensive literature survey [12], a survey in industry [11], and the 20 years of field experience of the main author as design analysis consultant. Some supplementary information has been extracted from another international survey [14] (the first survey concerned international companies but with their engineering design and design analysis functions mainly based in Sweden). The GDA process model reported here has been extracted from [13, pp. 37-39].

The GDA process model consists of three phases: analysis task clarification, analysis task execution and analysis task completion, as well as the activities and sub activities constituting each of the phases, see Figure 1.

The analysis task clarification phase consists of three activities. In the identification of the task (activity 1a, hereafter abbreviated to /1a/), the objective is to ascertain the task relevance and the actual need for launching the design analysis task. Once the relevance of the task has been agreed upon and the decision has been taken to continue, the preparation of the task content brief takes place /1b/. Once the task content brief is established, the analysis activity should be carefully planned and a formal document should be prepared and mutually agreed on (between the ordering engineering designer and the performer of the actual design analysis, the design analyst, or analyst for short), that forms the basis for the analysis execution /1c/. This should consist of a detailed plan of the contents described in the design analysis task content brief.

During the pre-processing /2a/ activity, the agreed task is processed further resulting in a representative engineering model (such as a geometrical model or a functional model) as well as the actual computational model for solution. In the next activity, solution processing /2b/, the analysis task is solved (executed) to generate the adequate amount of results needed for producing the required results. Results are extracted and assessed within the post-processing /2c/ with the purpose of providing adequate understanding of the general model behavior as well as accuracy and convergence in results obtained.

The third phase of the process is the analysis task completion, in which the first activity is the results interpretation /3a/, which relates to the interpretation and evaluation by the analyst of all relevant data and information that can be drawn from the analysis task execution. The outputs from the analyses are documented and communicated back into the overall engineering design/development project. This is done in the documentation and communication activity /3b/. In the final activity, integration of the results into the project /3c/, the design analysis task findings are being implemented into the engineering design task, from which it originates.

For each of the activities the core sets of sub activities are also presented in Figure 1.

Note that awareness that this core sub activities are not always enough to cover all aspects in every foreseeable design analysis task, thus resulting in adding additional sub activities when needed; denoted …-n. in Figure 1.

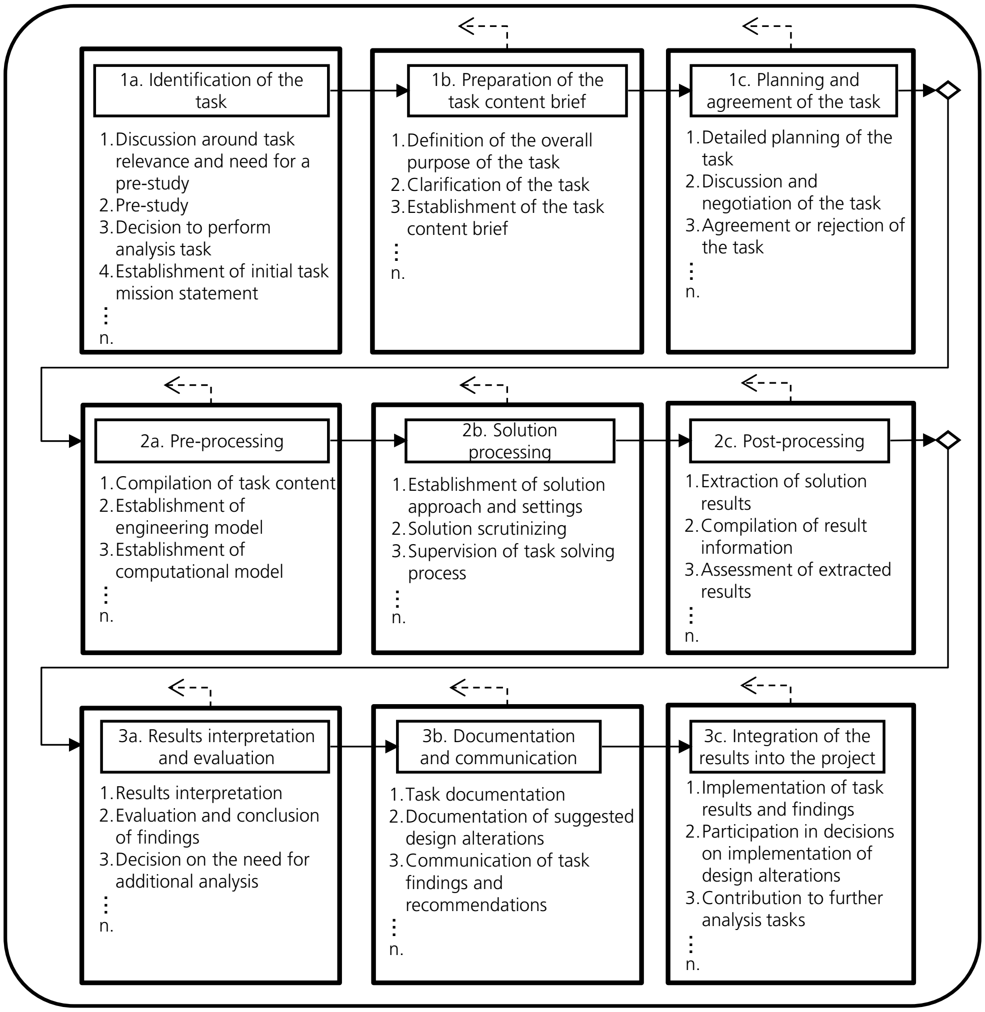


Figure 1. The GDA process model with defined phases and core activities [13, p. 39].

ADAPTING THE GDA PROCESS MODEL

Like all generic process models, the GDA process model needs to be adapted to each design analysis task. Several of the activities required to fulfill a given task are obvious because they are present in virtually every design analysis task (e.g. \2a-2c\). But in order to plan and establish relevant design analysis activities, it is necessary to base these decisions on experiences from prior projects together with applicable engineering knowledge.

It might be possible to develop specific process models for each context. This approach, however, has some disadvantages. Among others, it requires knowledge of four models instead of one, and, as mentioned above, there are in practice more than four contexts of design analysis tasks, which would require even more specific design analysis process models. Instead, we choose to focus on exemplifications of each context for which the GDA has been adapted. By studying these exemplifications, the person in charge of planning should be able to establish the structure of future design analysis tasks more easily. Moreover, if it is necessary to plan for a design analysis task in a context that is not exemplified here, the knowledge of how to adapt the GDA process model and the examples should also ease the planning task.[1] This is in a sense very similar to case-based learning used in management for example [15;16]: cases help understanding and using fundamental knowledge in disciplines where applications of this knowledge will differ greatly for each project. Furthermore, the GDA process model is flexible and can easily be used for iterative design analysis scenarios

[1] This means that the exemplifications below serve two purposes. They show that the GDA process model can deal with the four contexts, and they can help the practitioners structure their own design analysis task in any given context or combination of contexts.

as discussed in the second exemplification and for multidisciplinary applications.

Finally, to ensure a successful achievement of the design analysis task, it is also necessary to adapt the GDA process model to integrate the design analysis task into the overall engineering design and product development project. The issue of integration between the design analysis process and the engineering design process is of major significance for providing an increase in efficiency and effectiveness in engineering design and development of products. To that end, it is necessary to map out the interactions between the engineering designers and the analysts. This is made possible by analyzing the information workflow between the engineering design process and the design analysis process. An approach facilitating this mapping is described in [17]. For each exemplification, the mapping of the interactions between both functions will also be illustrated.

THE FOUR CONTEXTS

Design analysis most often aims at giving quantitative information on specific design parameters as a support for subsequent design decisions, i.e. a core activity within the “evaluation context”. However, as mentioned in the introduction, design analysis is also used in other contexts with different points of departure.

During the interviews in the industry [11], it was found that topology and parameter optimization was used as part of synthesis activities for concept and product definitions (that is, in an “explorative” context) by about half of the interviewed companies. Also physical phenomenon and feasibility studies as well as statistical and probabilistic evaluations can be considered as analyses in an explorative context.

All companies participating in the interviews use design analysis on a regular basis to evaluate product proposals of details, components and sub-systems and some of them also for complete systems (the evaluation context).

The companies also asserted that the validation of design analysis results were usually carried out utilizing physical testing (“physical testing” context) which in turn might call for additional design analysis activities. A closely related context to physical testing is the investigation of root causes of events occurring during use processes based on identified damages, failures or other specific related causes. Some companies even rely on design analysis as validation when other means of validation are not possible.

In order to be able to do so, verified and validated design analysis methods (i.e. established procedures, guidelines and templates) are usually developed (so called “method development”). The development of methods to facilitate the effort to introduce engineering designers to design analysis is also connected with the method development context.

The specificities of each context are described below.

Explorative analysis

It might be argued that in a broad perspective most design analysis tasks are of an explorative nature, since this implies that the design analysis activities aim at the determination of important design parameters associated with an existing or predefined design solution, thus providing the necessary results and insights to be utilized by the analyst and/or engineering designer to fulfil a specific purpose initially established for the actual design analysis task.

One of the single most important activities within the engineering design process is the creation of technical solutions - ranging from simple details to complex product systems and new working principles on which the product-to-be might be developed as described in [18;19]. In the engineering design literature, these activities are usually referred to as design synthesis or just synthesis for short. Traditionally, these activities are handled either by an engineering designer or by a design/development team, utilizing intuitive as well as discursive methods [18]. Resulting from the introduction of design analysis methods and tools, especially finite element-based, it has become possible for the engineering designer to utilize design analysis of the proposed design solution candidates to analyze different solution paths more thoroughly than ever before and thus be able to more or less fully explore the design solution space at hand. These analyses are traditionally performed by an analyst, who is either an in-house or an external consultant. In some cases the engineering designer might take over the role as analyst on his/her own, when predominantly confined to linear analyses [20]. However, it is not uncommon that analysts make suggestions for modifications or redesigns and in some cases also propose completely new design solutions. Finally, it is important to note that the synthesis tasks to be performed throughout an engineering design project are numerous, and not all of them lend themselves to design analysis in the given context due to impracticability and other difficulties associated with the actual synthesis tasks.

The explorative approach to synthesis has significantly contributed to deeper insights into the potentials provided by different design solution candidates and thus to more technically advanced solutions [14]. Adding statistical and stochastic as well as optimization methods and tools to this approach makes it also possible, at least theoretically, to fully explore the entire design space by determining the ultimate potential for each and every one of the design solution candidates; thus not only producing the optimal solution candidates but also providing the essential facts needed for an analysis of the robustness of the design solutions. In much of the current analysis software it is not only possible to more or less automate the entire approach, but also to generate the actual solution candidate by utilizing different statistical design exploration methods such as composite difference algorithms, space filling methods, design of experiments (DOE) methods, response surface methods (RSM) and goal driven multi-objective optimization methods such as shape optimization, and topology optimization [21;22]. A somewhat different, but closely related, approach to design synthesis as presented here is generative design, in which evolutionary algorithms are utilized in design synthesis – see [23].

Evaluation analysis

During the engineering design process, hundreds or sometimes even thousands of tasks are carried out in order to attain the final result in the form of a new or improved component, sub system or product. In a significant number of these tasks, decisions are made as to accept, modify or reject the design solution under investigation. The nature of these decisions might range from limited decisions on a single attribute to complex multi-criteria decisions in which the decision maker is facing a decision problem involving several, often contradictory, aspects of the solution candidate that have to be taken into account [24].

In industrial practice design criteria emanate from product specifications. A specification (singular) is a formalized account of the expected feature(s) a given solution candidate has to possess in order to fulfil the identified need from which the specification originates. In the "simpler" cases the engineering designer usually makes the decision on his/her own, while in the more complex cases decisions are made by teams, usually by cross-functional teams. The common denominator in all decisions is the access to knowledge of the "value" or "usefulness" of the solution candidate under examination. This knowledge is provided as a result of an evaluation of the solution candidate with reference to the expected performance expressed in terms of a design criterion. In engineering design practice, a number of approaches are utilized for such evaluations, ranging from subjective estimates based on the engineering designer's experience of similar designs, through testing of prototypes, to the use of design analysis and formal decision matrices.

When utilizing design analysis in design evaluation, the result obtained is usually confined to quantitative information on one or more specific design parameters used for an immediate decision or to be used in a subsequent multi-criteria decision activity.

The initial problem of any design evaluation is the difficulty of "translating" the often very complex and vague product specifications into fully operative evaluation criteria. For design analysis tasks, the process of translating is mainly carried out in the form of discussions between the engineering designer and the analyst. Exceptions from the described procedure occur when predefined design analysis criteria are supplied by an external source, e.g. by the engineering designer or the client, or by industrial standards.

Finally, in the words of Vincke [24, p. xv] regarding the important difference between optimization and multi-criteria decision-aid: "The first fact which should be noted when dealing with this type [multi-criteria, authors' comment] of problem is that there does not exist, in general, any decision (solution, action) which is the best simultaneously from all points of view. Therefore, the word 'optimization' doesn't make any sense in such a context; in contrast to the classical techniques of operations research, multi-criteria methods do not yield 'objectively best' solutions (such solutions do not exist)."

Physical testing

Since all design analysis results are derived from analysis models, the validation of these models through physical testing constitutes a key activity in most design analysis tasks. Validation in the given context is here defined as: "The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model." [25, p. 3]

In the planning for a physical testing project, the application of measurement systems such as strain gauges and load cells might call for additional design analysis activities to establish position, directions and levels together with other measurement parameters related to the actual testing activity.

Even during the most carefully planned physical test campaign, unexpected events may occur. In order to investigate the root cause of such events, design analysis is a powerful tool. Design analysis is also a powerful mean to perform post-test sensitivity and discrepancy studies in order to elaborate on deviations found when comparing data from physical tests and design analysis results.

Method development

Technology or method development, in the analysis terminology, is the development and validation of specific guidelines, procedures or templates[2] to follow when performing a design analysis task [12, p. 1188;20, p. 4].

The main purpose of the method development is to give support that has been verified and validated in order to ensure that the quality of a design analysis task or activity process or outcome. Verification means: "The process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model." [25, p. 3] (Validation has been defined in the preceding section).

Responsibility for the development of these methods usually lies with the design analysis department in close cooperation with a dedicated method development team. In some cases, representatives of external stakeholders also participate in these activities. The development of these methods should also include experiences gained and lessons learned from previous design analysis projects, including verification and validation before a method is approved for use in industrial practice. An example of such method development is presented in [26], in which a tool for establishing a quantitative measure of the risk of later encountering high-cycle fatigue (HCF), i.e. life-limiting vibrations of both rotating and stationary parts, was the goal. Available user interfaces and templates in commercial codes are often the results of performed method development tasks.

Beyond the strict quality assurance, other reasons can be invoked for method development in design analysis. One such

[2] Pre-developed code that supports or guides the engineering designer in performing design analysis tasks, e.g. from predefined settings available in traditional tools, to developed in-house scripts, and advanced usage of knowledge ware.

reason is when the experience and skills of an analyst are not sufficient to assure minimal risks and complete control of all of the activities constituting a design analysis task. This category usually occurs when the demand for full control of the entire analysis process is a must, often required by some external body such as a classification society, or in the development of military equipment; this may also occur in a company when extraordinary demands on product quality and safety exist.

Method development can also be initiated when a previously unknown design analysis task is to be solved, or when a new or improved design analysis technique is developed for existing design analysis tasks, and the objective might be to improve the performance of the design analysis process. For these tasks a technology development activity is performed by a team of analysts sometimes also including engineering designers and the managers for these functions, project leaders and, if applicable, representatives from external bodies. Since the result of such a technology development project is presented in the form of step-by-step activities, the term method is also valid here and used to denote the results of these activities.

More recently, method development has been used to allow engineering designers to undertake parts of, or the entire, design analysis activity traditionally performed by analysts. The initially expected outcome of this approach for companies has been decreased costs and lead times without jeopardizing the quality of the results obtained during the design analysis project [14]. Later experience has shown that the involvement of engineering designers in design analysis has given them deeper knowledge of the product technology, and improved their knowledge within design analysis, which in turn resulted in increased collaboration with the analysts [14]. Since the majority of engineering designers lack the experience and skills of an analyst, the design analysis tasks to be undertaken must be adapted to fit these constraints. The most frequent method development approach to accommodate this adaptation is to initially identify frequent design analysis tasks for which tailor-made guidelines or procedures can be developed and expressed in terms of step-by-step activities to be followed by the engineering designer. Templates developed through knowledge-based engineering (KBE) systems can also be utilized in parallel with the traditional design analysis tools, in order to provide the necessary support throughout the entire design analysis process. The nature of the design analysis tasks to be undertaken by engineering designers might range from very simple to complex. It is, in other words, fully possible to allow an engineering designer to undertake design analysis tasks of a complex nature e.g. involving elements of multi-physics analysis, without increasing the risks associated with the actual analysis task [14] when following a properly establish guideline procedure or template.

Responsibility for the development of these methods usually lies with a team of engineers, a method development team, responsible for the engineering design and design analysis activities within the company. These responsibilities also include the necessity of active participation of analysts in the training of the engineering designers as well as supervision of their analysis efforts, at least initially. The development, verification and validation of the KBE tools are also the responsibility of the method development team.

EXEMPLIFICATION OF THE CONTEXTS

As was mentioned in the introduction, the evaluation task is not exemplified as it is the most commonly described design analysis task. An example of an evaluation-oriented analysis task using the GDA process model (and the mapping of the interactions between engineering designers and analysts) is available in [17].

In each of the following exemplifications, the design analysis activities used for the fulfillment of the design analysis task are described, following the GDA process model. The main interactions between engineering designers and analysts (allowing for a better integration of the design analysis task into the engineering design and product development process) are numbered within parentheses. The adapted GDA process model used for each project is presented at the end of each section (Figure 4, Figure 9 and Figure 13, respectively).

Exemplification of a synthesis-oriented explorative analysis task – the design of a bumper

In designing a bumper beam system, as part of the overall crash management system, an important task is to assure accurate predictions of the consequence of various crash scenarios given different objectives. For low speed impacts, up to around 15 km/h, the focus is on evaluating repair cost of the damaged bumper system and for intermediate speeds between 15 and 40 km/h the main focus is pedestrian safety. For crash scenarios at higher speeds, above 40 km/h, the focus shifts to driver and passenger protection. A number of regulations, standards and protocols in Europe, e.g. the United Nations Economic Commission for Europe Regulation No. 42 (ECE R42), the Directive 96/79/EC and Regulation No. 78/2009 of the European Parliament and of the Council, the diverse test protocols of the European New Car Assessment Programme (Euro NCAP) and of the Allianz Center for Technology (AZT Automotive GmbH), are available that outline various scenarios with which the system should comply.

In this example a center pole impact of the mono rear bumper beam is introduced; see embodiment in Figure 2. The purpose of the analysis scenario is to study the intrusion during a low speed impact in order to reduce the insurance cost, which is directly related to the predicted level of damage occurring during the impact scenario. Higher intrusion indicates increased risk of damaging costly parts in the rear end of the car resulting in higher insurance costs.

The initial information from engineering design to the design analysis activities (1) is a short description of the problem at hand, and since the request came at such an early stage of the design work, the design space is quite open for alternative design solutions. During the following discussions

/1a.1/ it was found that a synthesis-oriented explorative design analysis task would be the preferred approach. The decision /1a.2/ to perform the design analysis based on the discussion were summarized and documented in a preliminary mission statement /1a.3/, which was communicated back to the engineering designer (2).

During the next activity, to further clarify the task /1b.1/, discussions within the project team regarding general conditions of the analysis scenario (3) took place. The analysis scenario consists of a 15 km/h central impact against a rigid pole with a radius of 90 mm as displayed in Figure 2. The type of result to be extracted was agreed upon as well as the various input data of the pole and how the interface between the bumper system and the remainder of the car should be established /1b.2/, see Figure 2.

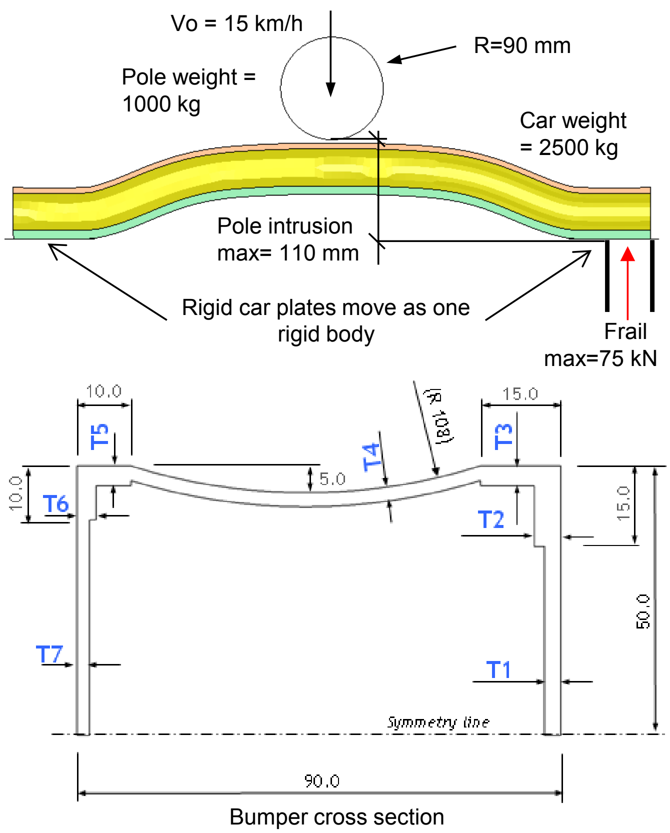


Figure 2. Top: constraints setup. Bottom: model parameters (courtesy Validus Engineering AB).

Furthermore, decisions were also taken regarding the constraints and the output quantities, such as the objective of mass and the constraints as shown in Figure 2 (top).

The objective of the design analysis task was set to minimize the weight while complying with constraints on intrusion and force into the car crash rail /1b.3/. Also the project time constituted a constraint that demanded a specific analysis method to be used in order to keep execution time and related costs as low as possible. The information known at this point in time was put into the task content brief for final acceptance of the task /1b.4/.

However, due to the time span between the preparation of the task content brief and when it was actually decided to initiate the execution of the analysis project, there had been some development on other production related engineering design activities (4) constraining the design freedom on thickness parameters, as shown in Figure 2 (bottom), to some interval values for 7 defined sections whereas other parts were fixed /1c.1/. This was reflected in an updated version of the task content brief (5) before the final planning and agreement on the task was finalized (6).

The geometrical model available was transferred from the engineering designer to the analyst (7) and the computational finite element analysis (FEA) model was established /2a.2/ with shell elements that were found adequate for an evaluation of the response. The car and the pole were both represented as rigid parts, implying that they are only allowed to translate in the x-direction, meaning that energy during the impact should be absorbed by the bumper and transmitted into the car plates. The model setup was communicated to the project team (8) to make sure that no new information was available before the solution processing was initiated. The solution process set out for this task was to use a d-optimal-based design space investigation with 13 points based on full factorial DOE with 5 levels to establish the base configuration for a linear metamodel-based RSM optimization. Maximum number of iterations was set to 8 and tolerance on acceptable results was set to less than 1% change in both mass and thickness compared to previous iteration optimum /2b.1/. Thus the total number of analyses scrutinized was $8 \times 13 + 1 = 105$ /2b.2/ and the extracted results /2c.1/ show that two feasible designs, 1 and 3, exist for the intrusion constraint, see Figure 3 (left). Iterations 7 and 8 are close to feasible /2c.2/.

The results were post-processed and the accuracy predictions in the metamodel were investigated by performing an additional analysis of iteration 3 that showed that the predicted value corresponded to the calculated value /2c.3/. The results were then further assessed /3a.1/, and the conclusion was that it could be shown that the parameter configurations of iterations 7 or 8 resulted in lower masses than the feasible iterations did /3a.2/. These findings were communicated back (8) to the project team with the purpose of challenging the constraint level set on intrusion. However, this was not found practicable and therefore the current set of results was documented. The main results were thus collected in a documentation describing the task performed /3b.1/, and the following main findings were reached:

- The design analysis resulted in a feasible design at iteration 3 with a mass of 3.79 kg. This is established through 3 successive generations of linear RSMs and 40 FEAs.
- Additional reduction in mass (about 1.6%) to 3.73 kg was found in the “nearly” feasible designs in iterations 7 and 8 with 110.2 mm and 110.1 mm intrusion respectively (110 was the criterion), see Figure 3 (right).

These findings were then communicated /3b.2/ and presented to the project stakeholder (9) with the message that there is a possible gain in mass reduction if some adjustment could be allowed on the intrusion constraint against the rigid pole as displayed in Figure 2. The outline of the workflow during the bumper design analysis task is shown in Figure 4.

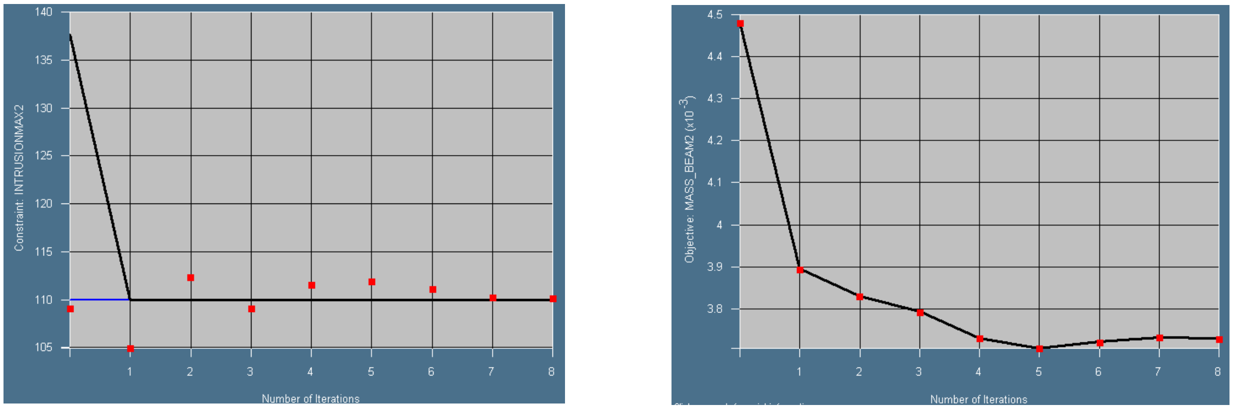


Figure 3. Left: Intrusion as a function of iteration. Right: Mass as a function of iteration (courtesy Validus Engineering AB).

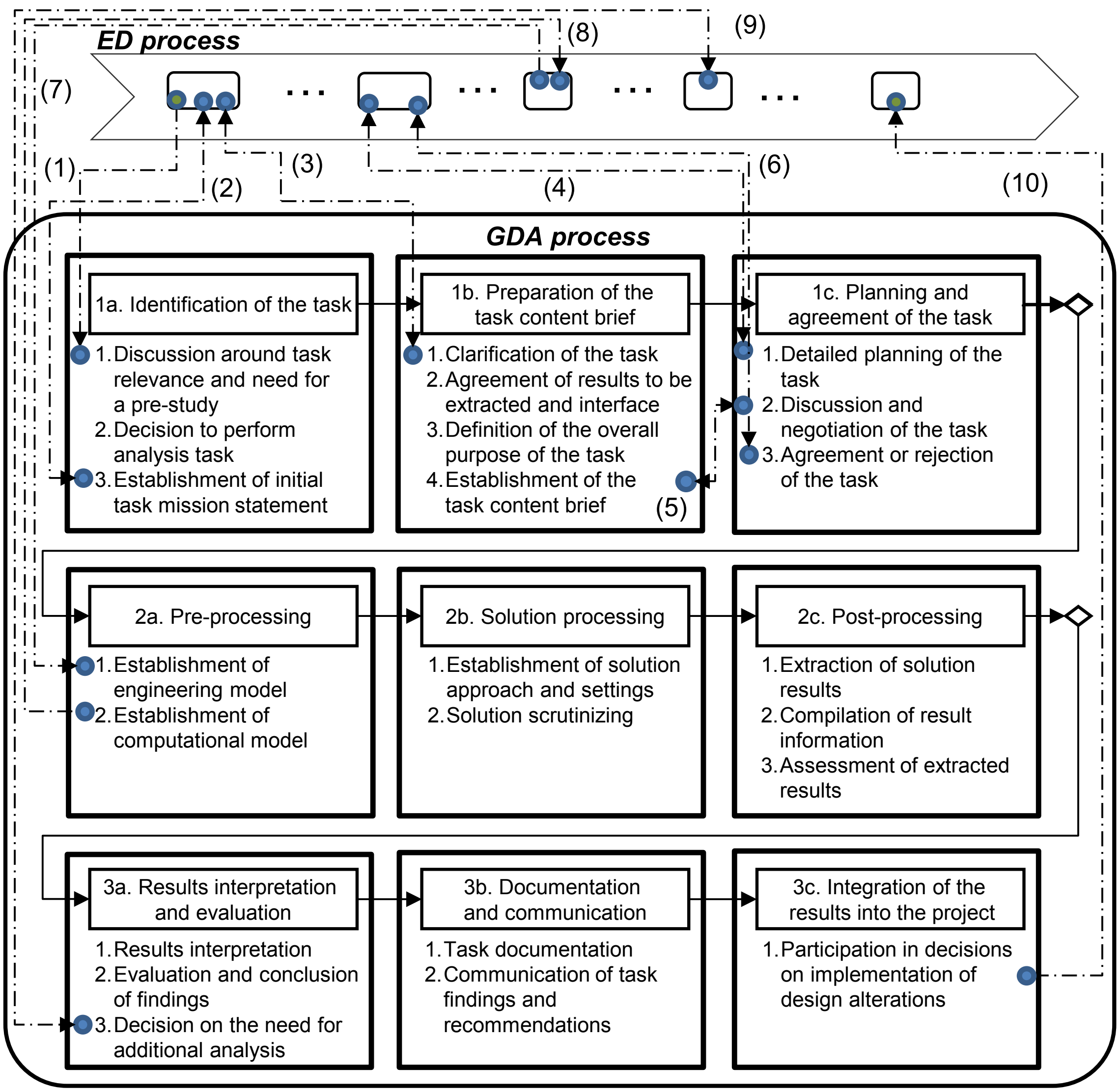


Figure 4. The design analysis activities during the bumper design analysis task (ED: engineering design).

Exemplification of a physical testing – acceptance testing of a device transportation system

This example presents one of the final physical acceptance tests of a device transportation system (DTS) [11;27] developed for a semiconductor device, hereafter referred to as the "shipped device", see Figure 5. The shipped device is sensitive to high acceleration levels and is to be shipped by different means of transportation, which places demands on the DTS (see Figure 5 for a schematic overview of the DTS that insulates the shipped device from vibrations and shocks during shipment). The main demand on the performance of the DTS is that the acceleration level on the shipped device at any point and at any time should not exceed specified levels. This includes both horizontal and vertical shock loads as well as vibration. The vertical shock demand is selected for exemplification in the current publication.

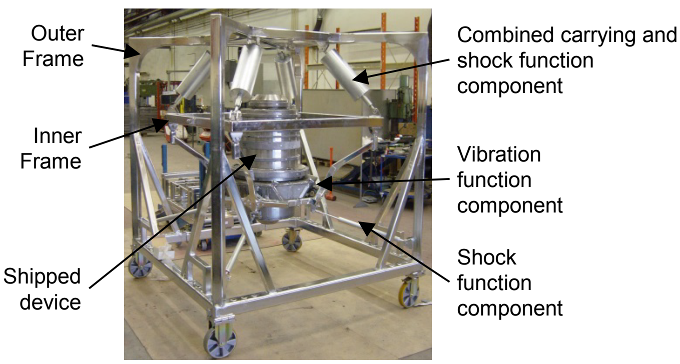


Figure 5. Overall description of the shipped device as well as the DTS (courtesy Validus Engineering AB).

A total of three different types of tests were performed:

1. Collision test
2. Drop test
3. Vibration test

In this example the drop test scenario has been selected for the illustration of the workflow during a physical test. During the identification of the design analysis activity /1a.1/, the appropriate combination of design analysis approaches to be used in the validation comparison of the obtained design analysis results to the physical test data was discussed (1). The limitations and potentials of the selected approaches were assessed in order to estimate the effect uncertainties would inflict on the analysis results in relation to the design analysis activity ahead, based on the present state of knowledge of the actual project and also within the company emanating from the preceding design activity /1a.2/. In the current case, approaches based on multi body simulations (MBS) and FEA were compared and a decision was made to include assessments from both types of approaches in the design analysis task (2).

The purpose of the design analysis task was defined as to support the testing of the drop test scenario /1b.1/. The drop test was divided into three phases: free fall, impact and retardation and the specifications established that the drop test should be performed from a drop height of 100 mm to avoid damage to the floor and local damage of the DTS /1b.2/. The test scenario and placement of measuring devices of the strain gauges, accelerometers as well as displacement and velocity transducers on the structure is shown in Figure 6 (left). The initial proposal on the number and placement of measuring devices is based on a study of available design analysis results and documentation from the design work /1b.3/. The task content brief was established with the above established information /1b.4/. Within the detailed planning of the design analysis task it was concluded that properties of a special made pallet, see Figure 7 (left), supporting the DTS during the testing would influence the outcome of testing /1c.1/. Therefore, it was put forward to the engineering designer to also include a pre-test analysis assessment of the pallet to the current design analysis task (3). The task content and approach was agreed upon and the execution of the design analysis task was initiated /1c.3/.

The design of the pallet was provided by the engineering designer (4). The representations of the shipped device and DTS were also extracted from the development project (5). A single complete computational model of the pre-test details was established /2a.2/ and the solution was processed as a pre-test analysis /2b.1/ in order to assess whether it was able to sustain the loads during the various test scenarios. The extracted state of stresses /2c.1/ from the static loading is displayed in Figure 7 (right); this was communicated back to the project as intermediate results for review (6). Note that only the outer frame and pallet are displayed here for clarity. The interpretation and conclusion of the various cases studied was that the pallet design proposed was capable of withstanding all load cases /3a.1/. These findings were communicated back to the project for further design and manufacturing of the pallet and preparing it for physical testing (7), as well as for initiating actual design analyses of the validation scenario using both ADAMS software (MBS approach) and LS-DYNA software (FEA approach) (8). Computation models were established /2a.3/ and initial analyses were performed for the drop test scenario similar to the physical testing /2b.2/

Based on the post-processing of the analysis results from the LS-DYNA analysis /2c.2/, further information regarding the originally proposed measuring points was reviewed and some small changes were proposed /3a.2/. It was decided to incorporate them in an updated computational model (9) that resulted in the actual test setup as shown in Figure 6 (right) with the DTS mounted on the pallet prepared for a drop into a 1-meter-thick concrete floor from 100 mm /2a.4/. In the further right hand side of Figure 6 the resulting accelerometer positions are shown.

The execution of the actual physical test scenario gave the results presented as red curves in Figure 8. Dimensionless quantities are used in the graphs, and ±1 represents the criterion on the shipped device. The measurement point is at the top of the shipped device. These results were communicated to the analyst (10) and used in the comparison between the test data and the extracted analysis results from the ADAMS analysis /2c.3/ as shown in the upper picture in Figure 8, which shows quite good agreement in the free fall and retardation part of the event /3a.4/. However, the peak at impact is not captured accurately enough to judge validity. The comparison /3a.4/ between the test data and the LS-DYNA analyses /2c.4/ results shows a good correlation for the peak values.

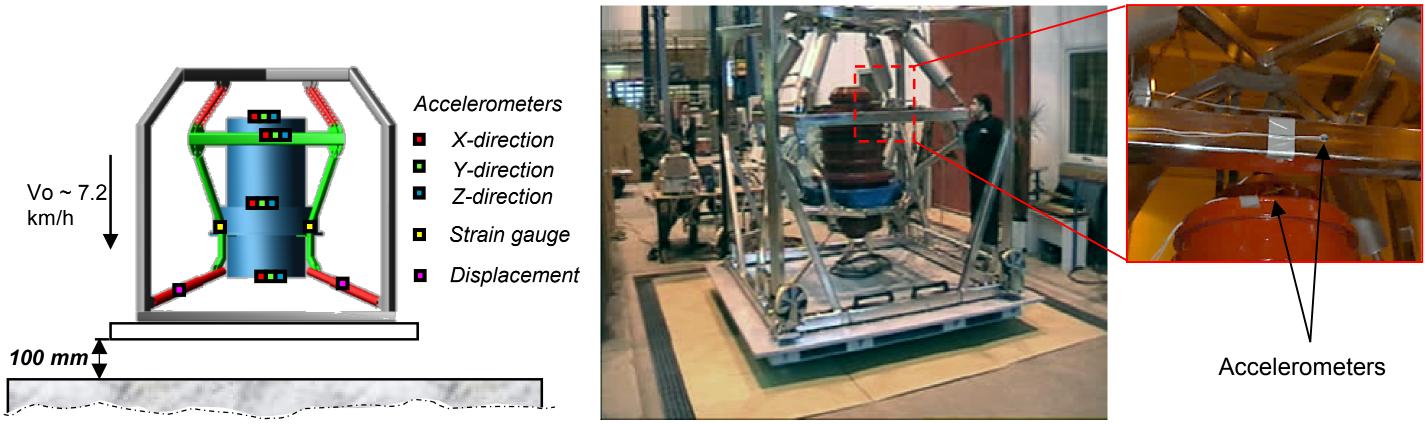


Figure 6. Drop test description and placement of measurement system (accelerometers, strain gauges and displacement). Left: Engineering model. Right: Physical test setup (courtesy Validus Engineering AB).

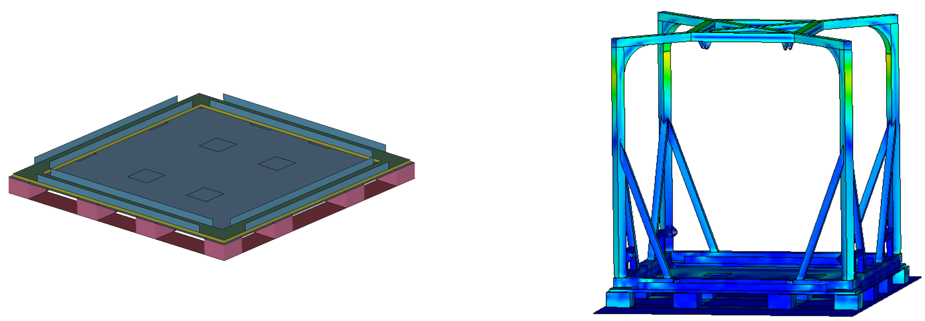


Figure 7. Left: pallet design. Right: stress state from static loading scenario (courtesy Validus Engineering AB).

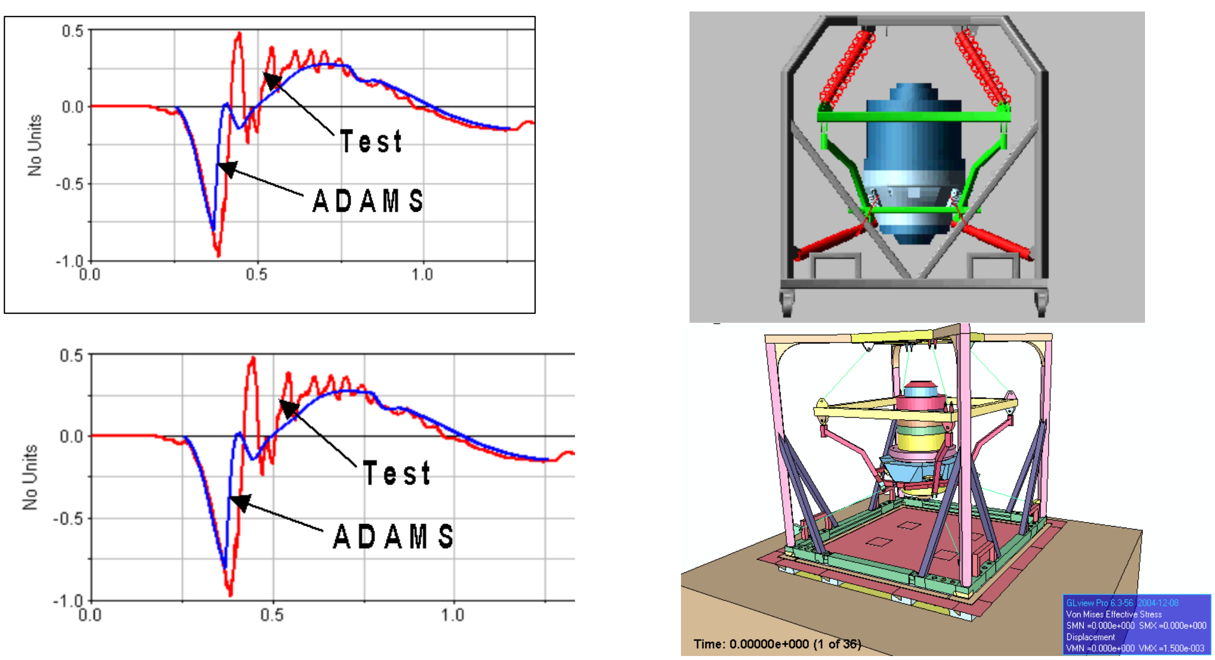


Figure 8. Top: ADAMS model and results comparison with test data.
Bottom: LS-DYNA results comparison with test data (courtesy Validus Engineering AB).

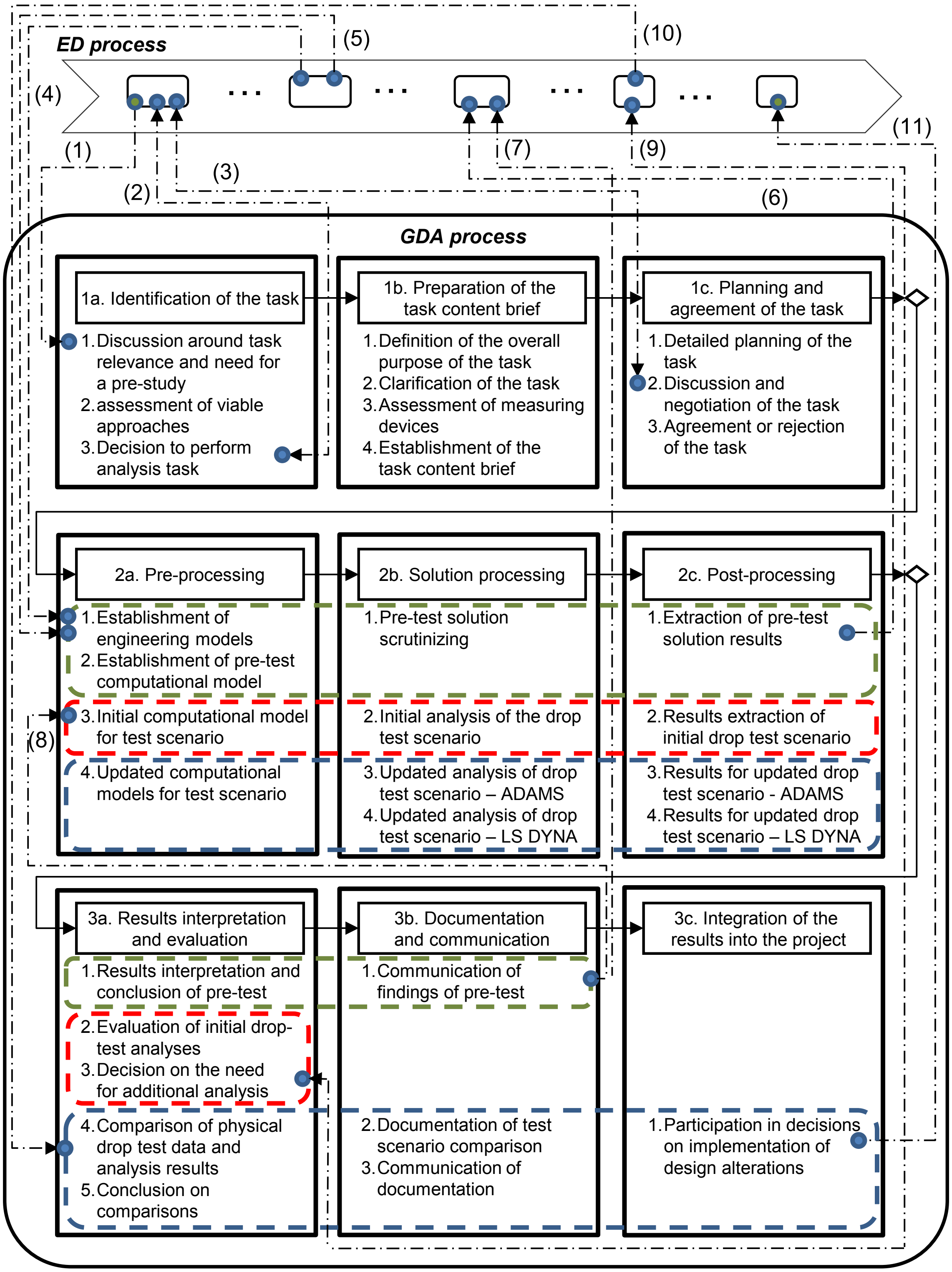


Figure 9. The design analysis activities during the physical testing of the DTS (ED: engineering design). The green dashed rounded rectangles enclose the pre-test analysis steps. The red dashed rounded rectangles enclose the analysis of the initial test scenario. The red dashed rounded rectangles enclose the analysis of the updated test scenario. These three analyses have been performed sequentially as described in the text above.

The conclusion drawn from the validation comparison /3a.5/ is that neither analysis approach is capable of capturing the whole event nor alone able to provide the necessary facts needed for the acceptance of the criterion. Instead, both the ADAMS and LS-DYNA analyses are capturing different aspects of the event to describe adequately the complete drop test scenario. The ADAMS analysis /2b.3/ is used to predict the overall information from the event and LS-DYNA analysis /2b.4/ is used to predict the acceleration levels at and after impact with the floor. This conclusion is documented /3b.2/ and communicated /3b.3/ to the project team by email as well as participation in a final product acceptance meeting where the analysts as well as the engineering designers involved in the testing were present to elaborate on the inferences from the validation comparisons (11). The outline of the workflow during the physical testing of the DTS is shown in Figure 9.

Exemplification of method development – development of a template for analyzing a valve and seating for a combustion engine

In the automotive industry, new and more extensive environmental demands on emissions from combustion engines force manufacturers to optimize performance of their engines. One component in such an engine that is especially affected by these efforts is the exhaust valve and its seating, see an example Figure 10. The traditional procedure in the design of an exhaust valve seating arrangement is that the engineering designer generates a design solution that is handed over to the design analysis department for evaluation.

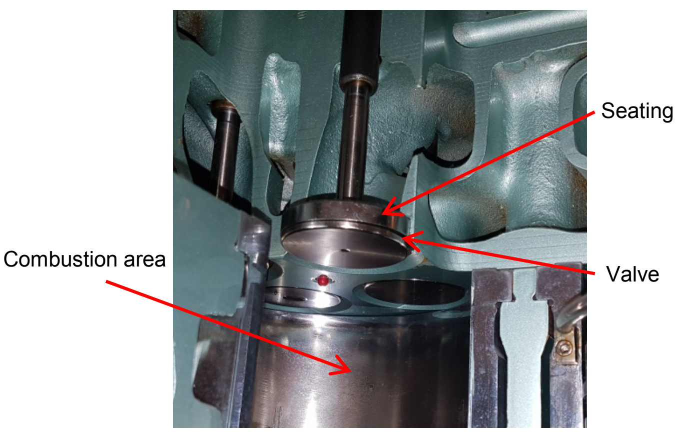


Figure 10. Exhaust valves and seatings of a diesel engine.

It was decided that the engineering designer in charge of the design and development of the exhaust valve and its seating should carry out the generation and evaluation of the concepts on his/her own. One reason for this approach was that additional projects of the same nature were expected in the future. As the engineering designer usually lacks deep insight into design analysis, it was expected that performing design analysis on his/her own would introduce major problems that would demand extensive support [20]. To be able to handle these problems and thus allow the engineering designer to generate and evaluate an extensive number of different exhaust valve seating concepts, it was decided that a template based design analysis (TBDA) should be introduced. TBDA is defined in [14] as a pre-developed code that supports or guides the person performing design analyses tasks, e.g. from predefined settings available in traditional computer aided engineering (CAE) tools to scripts developed in-house and advanced usage of knowledge-based systems (KBS).

In the example presented here, a template is developed for the design analysis of the exhaust valve seating design, utilizing method development. Developing such a template generates high development costs, but as such a template can be used for a number of different sizes of combustion engines, the cost for the development could be accepted.

During the project planning, discussions around task relevance and the need for a pre-study (1) was agreed upon. A pre-study /1a.2/ was performed. After evaluating the results from the pre-study and the establishment of a preliminary mission statement (2), it was decided that a method development (3) for this type of design task (conceptual exhaust valve seating designs) should be performed. Since the method development should result in a template to be used by an engineering designer who does not have in-depth knowledge of design analysis, there were many different types of issues to be resolved.

One important issue was the quality aspect of the template and how to ensure that the users can only do what they were allowed to do. It was decided during the definition of the overall purpose of the task (4) that the implementation of KBS into the developed template should provide the necessary quality assurance (QA), /1b.2/. A routine for ensuring the QA of the developed template was formulated, /1b.3/. It was also essential to make the implementation of the template user friendly by developing a custom made user interface /1b.4/.

During the detailed planning of the task (5), the final settings for the model were agreed upon. An agreement on how the user should utilize the template involving sub activities was now completed and an agreement or rejection to develop the template was decided /1c.2/.

The user interface, see Figure 11, and the possibility to read and write from a spreadsheet were utilized in the establishment of the geometrical and computational models as well as the KBS elements (rules, checks and constraints) (6). were integrated and connected to the geometrical and computational models /2a.2/.

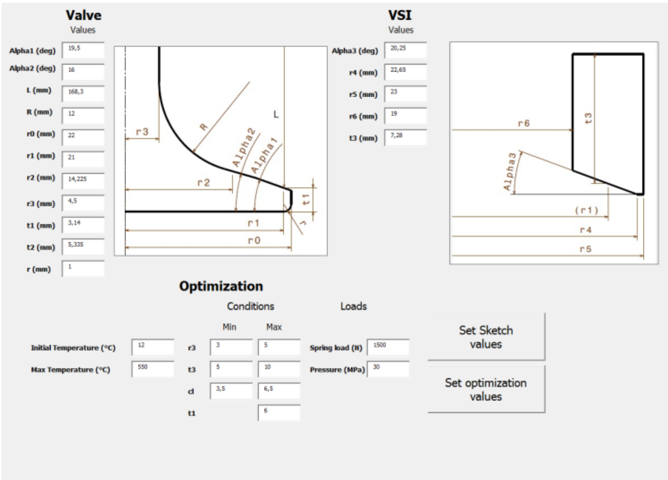
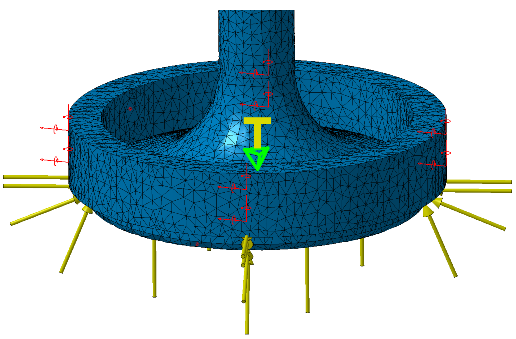
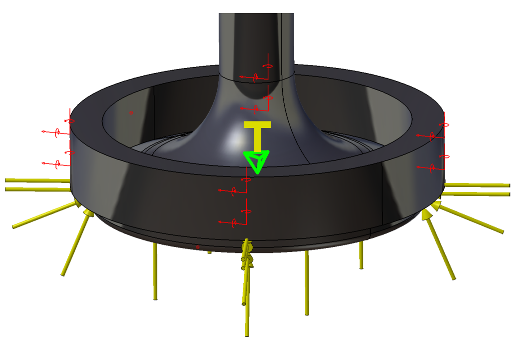


Figure 11. User interface.

The computational model /2a.3/ was prepared. Tolerances of the mesh, boundary conditions and contact properties, and the materials were implemented into the computational model – some of the outputs as presented to the user are illustrated in Figure 12. The necessary settings for the analysis execution was defined /2b.1/.



The computational model – mesh



The computational model – boundary conditions

Figure 12. Some outputs from the template.

The computational model was now ready for solution and the solution scrutinizing /2b.2/ was performed. Note that during this activity the method development involved a number of analyses in order to cover established design space. During the extraction of solution results /2c.1/, "sensors" (extreme values in form of parameters) and predefined plots were implemented. The sensors are also utilized for assuring the quality, by comparing the result with the agreed settings for the specific task /2c.2/. If any values are outside the valid range, warnings appear, informing the user that the given solution is not valid /2c.3/. With this type of method development, consistency of both the geometrical and the computational model is important. During the same phase, an extra verification was performed with external analysis software /2c.4/. Under results and interpretation and evaluation, the template was evaluated and conclusion of findings were discussed in the method development group (7). Validation of the developed template was made by instructions from the previously developed routine (/1b.3/) /3a.2/.

After the validation was completed, task documentation (8) was made, containing the full process of the method development as well as the background information on its purpose. As the developed template was intended to be used by different users, a user guide (9) was written to support the engineering designer when performing analysis utilizing the template. The last sub activity in the method development is finalizing the method development (10) and implementing the template (11) for use in the engineering design process. The outline of the workflow of the method development of a template for the design analysis of the exhaust valve and seating is provided in Figure 13.

CONCLUSION

Being able to execute efficiently and effectively design analysis tasks in different contexts is important. The exemplifications above show that the GDA process model can be successfully adapted to accommodate these goals. As the GDA process model shares several activities with other design analysis process models, these latter models might also manage efficiently contexts other than explorative and evaluation-oriented ones. It would be beneficial in any case to check systematically design analysis process models for different contexts and devise specific guidelines for them when necessary.

Learning to adapt a process model or a methodology by use of cases is not yet much developed within the engineering design discipline. Such an approach might be interesting to enhance learning and understanding of engineering design process models.

The GDA process model has been used in more than 50 industrial projects within the different contexts mentioned. However, the guidelines presented here to adapt the GDA have not been tested with analysts not involved in this research. This should be the next step, as ease of use and implementability are keys for the diffusion of methods and methodologies [28;29].

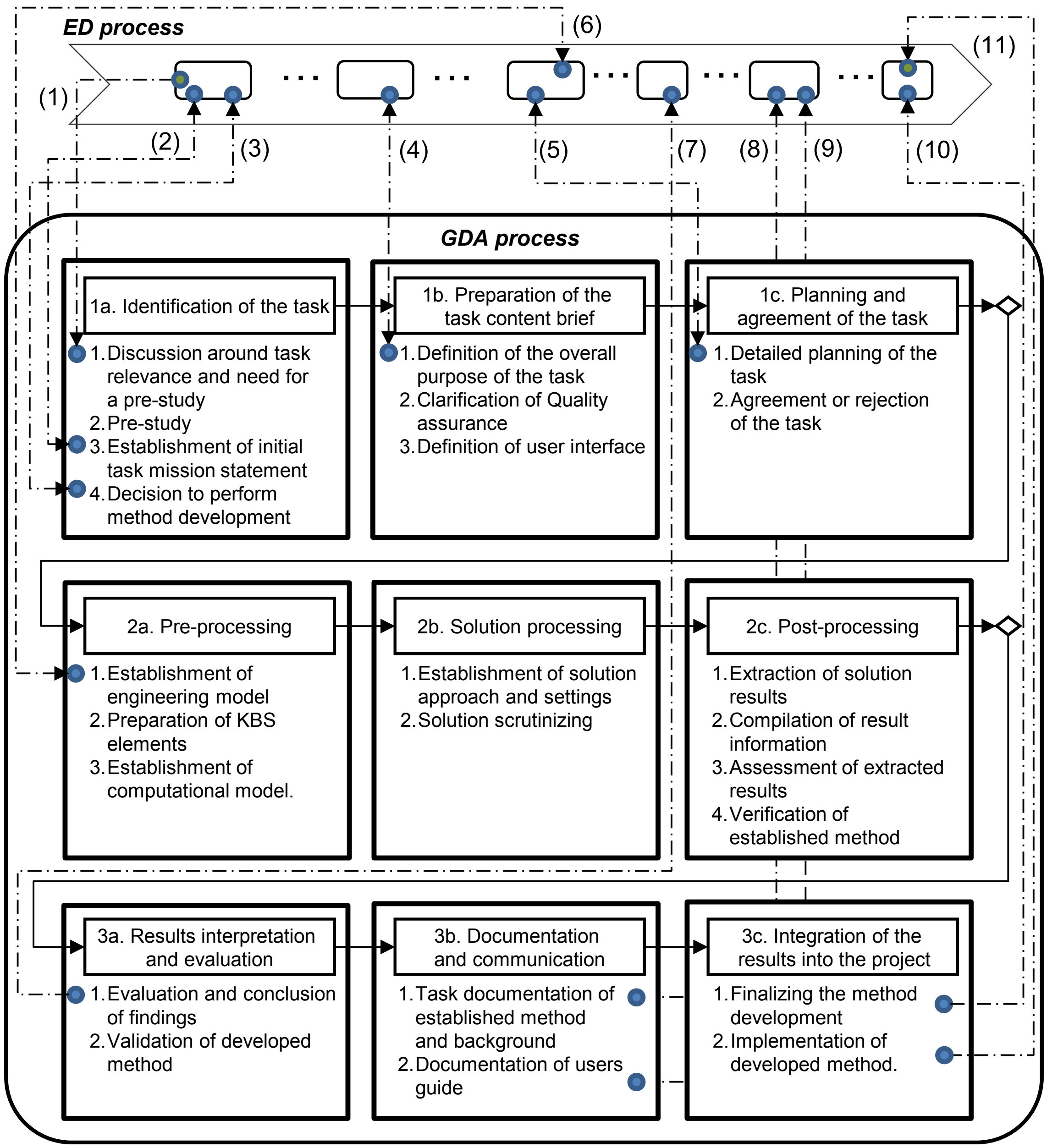


Figure 13. The design analysis activities during the method development of a template for the design analysis of exhaust valves and seatings (ED: engineering design).

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