ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

INVESTIGATION OF THE EXOGENOUS FACTORS AFFECTING THE DESIGN ANALYSIS PROCESS

Martin ERIKSSON, Damien MOTTE
Lund University, Sweden

ABSTRACT

Computer-based design analysis activities are an essential part of most product development projects in industry. An effective integration of the analysis activity into the product development process is therefore very valuable. The current work shows that design analysis activities are constrained and influenced by many elements from their working environment. Factors exogenous to the design analysis activity, but that have an important effect on it, are identified and grouped along their levels of influence on the activity: some appear within the development project, some are at the enterprise level, and some are outside the sphere of the enterprise. The proposed classification has the advantage of indicating what leverage a stakeholder can have upon such factors: the farther from the analysis activity context, the more difficult it is to act upon them. Furthermore, a guideline presents how to deal with these factors during design analysis planning and execution within a product development project and in alternative enterprise configurations. Being aware of those factors should prevent fastidious iterations resulting from a poorly planned and organised design analysis task.

Keywords: simulation, integrated product development, design process, design analysis

Contact:
Martin Eriksson
Division of Machine Design / Lund University
Department of Design Sciences LTH
Lund
SE-221 00
Sweden
martin.eriksson@mkon.lth.se

1 INTRODUCTION

In the large majority of development projects, solution proposals are evaluated with the help of computer-based design analysis tools. The more advanced the project is, the more detailed and complex the analysis can be, and, often, the analysis activity is performed by a specialist, employed by either the development enterprise or an engineering consulting (EC) company. The place of these analyses in a development project is important as they contribute to the exploration of design properties; evaluation and verification of design solution proposals; to the improvements/modifications of the studied design; to support the validation of the developed design; to reduce the required use of physical testing, etc. At the same time, computer-based design analyses are time-consuming, and much iteration is necessary between the engineering designer and the analyst before a final design is approved. A correct and effective integration of the analysis activity into the development process and in its working environment in general is therefore very valuable. However, apart for some early works at a time when computer-based design analysis was in its infancy (e.g. Ciarelli, 1990; Bjärnemo et al., 1991; Goss, 1991), this integration aspect of the analysis task into product development has been prioritised neither in the engineering design literature (see e.g. Pahl et al., 2007; Ulrich and Eppinger, 2012) nor in the Finite-Element Analysis (FEA) community, apart from a few works (see e.g. Leahey, 2003; Adams, 2006).

In order to ensure a correct and effective integration of the design analysis activity, several elements are necessary, such as an adequate design analysis process model, a suitable organisation, software and hardware, see (King et al., 2003) for a full framework. It is also important to have knowledge of the many *factors* that constrain and influence it. Several research works where factors that affect the engineering design situation or context have been surveyed have been done within engineering design, see e.g. (Hales, 1987; Hales and Gooch, 2004; Hubka and Eder, 1996, pp. 138ff). In this work, we focus on the description and the handling of the factors that particularly affect the design analysis. Specifically, we address *factors that are exogenous to the design analysis activity itself but that have an important effect on it*, that is, that can significantly affect analysis planning and that would negatively affect its execution and results if neglected. One example is the use of standard methods imposed on the analysis by a third party in a military equipment or an off-shore project: at the same time that it guides the design analysis activity it also constrains the degrees of freedom of the analyst. This paper presents a description of such factors and proposes a guideline for dealing with them — and acting upon them when possible— in a development project.

This guideline is first presented in the traditional setup of a developing enterprise that has its own analysis department. In many cases, however, analyses take place in alternative enterprise configurations where analysis is outsourced to engineering consulting companies (EC companies for short), or to suppliers in charge of the development of functions or components of the technical system. For these different enterprise configurations, the factors are affecting the analysis activity in different way. Alternative utilisations of the proposed guideline for a set of typical enterprise configurations are therefore also presented.

2 METHODOLOGY

The factors presented have been extracted from diverse sources. Some factors have been established from a series of interviews with Swedish manufacturing and consulting companies, where best practices could be observed. The interviewed persons in each company were generally responsible for performed design analyses activities, and in some of the companies also responsible for all of the product development departments. The complete interview approach is described in (Eriksson et al., 2013). Other factors have been taken from the literature. Because works on such an integration were found to be scarce, an extensive literature review was carried out (Motte et al., 2014). On the engineering design and product development side, the review is based on most *ICED conferences* proceedings (1985-2011), the ASME's proceedings of the *Conferences on Design Theory and Methodology* (DTM), *Design Automation Conferences* (DAC) available to the authors (spanning from 1990 to 2011), the *Journal of Engineering Design* (1994-2011) and *Research in Engineering Design* (from 1989-2011). The design analysis review is mainly based on the proceedings of *NAFEMS World Congresses* (1999-2011), *International Ansys Conferences* (1987-2012) and *Simulia Community Conferences* (2007-2012), as well as the design analysis journals *Finite Elements in Analysis and Design* (1985-2012) and *International Journal for Numerical Methods in Engineering* (1985-2012).

The factors elicited are the ones that have been deemed to have the most influence on the analysis process. The list of these factors is also not meant to be exhaustive. The overall design analysis process model to which those factors apply is presented next.

3 THE DESIGN ANALYSIS PROCESS MODEL

Design analysis process models consists classically in three main design analysis activities: *Analysis task clarification* (step 1), *Analysis task execution* (step 2) and *Analysis task completion* (step 3). The *Analysis task clarification* activity consists of the identification of the design analysis task, followed by a step of preparation and adoption of a task content brief. Within the *Analysis task execution* activity the computational model is prepared (pre-processing), executed (processing) and the result accuracy is assessed. The design analysis task is completed in step 3 by interpreting and evaluating the established results and the computational model behaviour, and the outputs are integrated back into the project.

4 FACTORS INFLUENCING THE DESIGN ANALYSIS PROCESS MODEL

4.1 Overall model

The criterion held for qualifying an element as a *factor* influencing the process model is the following: *an element exogenous to the design analysis activity but having an important effect on it*.
The factors significantly affecting the design analysis process are described below, grouped along their levels of influence: some appear at the development project (time, costs, etc.), some are at the enterprise level, and some, such as legal aspects and standards, are outside the sphere of the enterprise. The factors are represented in Figure 1. Such a classification has the advantage of indicating what leverage a stakeholder can have upon them: *the farther from the analysis activity context the more difficult it is to act upon those factors*. That means that the influences from the factors at the project level can be more easily managed than the influences from the factors at the enterprise level. The factors at the environment level can almost never be acted upon at the design analysis level. Each of the factors is next described according to the level it belongs to.

4.2 At the environment level

The enterprise operates within a certain environment that constrains directly and indirectly the design analysis activity. The most important of those factors are the following:

- ***Legal and environmental regulations***: The legal and environmental regulations to which the developing enterprise has to relate and that also set bounds for the design analysis activities. Note that this headline also includes products and systems which are protected under governmental laws regulating security issues, as well as those measures which are taken in individual enterprises in order to protect their products.
- ***General industry and certifying standards***: The industry-gained experiences and knowledge together with certifying agency contributions are assembled in various forms of standards. These standards provide generally accepted methodology approaches, working procedures and means of assessing their accuracy. In many industrial branches, these standards must be followed, by injunction of the client (if EC company) or by certifying agencies.
- ***Customer standards***: In some cases, the customers themselves have established standards that analysts must follow, in the format and extension agreed.
- ***Hardware and software suppliers***: The capabilities (functionality, licences, training, etc.) offered by the hardware and software suppliers and the choices they make relative to further hardware and software development have a huge influence on the organization of the analysis department, and on the planning and execution of the design analysis activity.

4.3 At the enterprise level

The enterprise resources such as *hardware*, *software* and *procedures* and *knowledge* as well as the enterprise's *organisation*, available *competence* and the *quality assurance (QA) assessment* all define the factors that at the enterprise level constrain the design analysis activities.

- ***Hardware***: Appropriate hardware solutions such as desktop computers, computing clusters and grid computing environment allow for efficient execution.

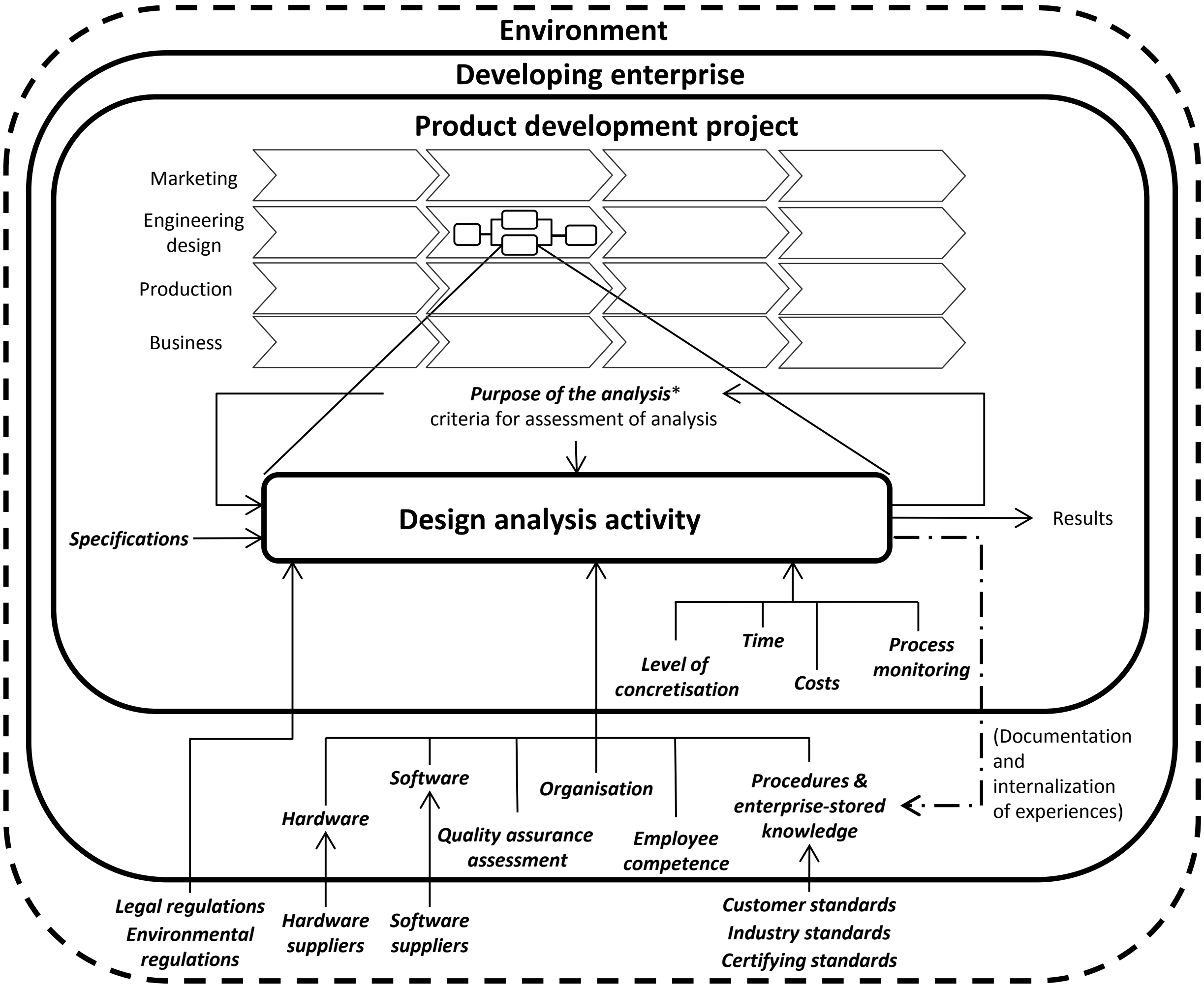

Figure 1. Factors affecting the design analysis process

- ***Software***: Certified in-house tools and commercial software are essential throughout the design analysis activities for an effective and consistent execution. Furthermore, software aimed at data and information management within project activities as well as for global enterprise accessibility are essential for successful integration of engineering design and design analysis processes.
- ***Procedures and enterprise-stored knowledge***: Presence of enterprise-stored knowledge allows for utilisation of relevant experiences gained from previous performed activities. Established procedures, based on the stored knowledge (through knowledge management), are important assets available to all stakeholders of the design analysis activities, thus providing guidance on how to conduct the analysis activities.
- ***Organisation***: The constitution of the enterprise organisation and its coordination mechanisms impact the way the design analysis activities are planned and executed. In particular, the separation distance, deeply correlated to the communication frequency between engineering designers and analysts, plays a very important role.
- ***Employee competence***: Adequate competence among analysts improves the likelihood of successful completion of the activities.
- ***QA assessment***: The aim of the QA assessment is to establish confidence in the performed work and subsequent interpretations of the results by the analyst, utilising methods such as verification & validation (V&V, ASME, 2006). The verification process consists of activities such as self-assessment performed by the analyst and planned quality checks, performed by another team member with appropriate competence, with the purpose of verifying that the computational model, assumptions and established results are accurate. The validation process consists of activities determining how well the performed work accurately models the real world.

4.4 At the project level

The product development project-related factors such as *purpose* and *specifications* of the design analysis activities, the *level of concretisation* of the product-to-be, and *time* and *cost* establish the frame in which design analysis activities are to be conducted. Furthermore, the *monitoring* of the process is an essential ingredient for the successful fulfilment of the task.

- ***Overall purpose***: The overall purpose of the design analysis task is defined within the development project. There are several possible origins of the task and therefore several purposes. The initiation of the task can be connected with the evaluation of criteria within the product specifications, the assessment of a design proposal, or can be triggered by a re-design or a prior analysis. The purposes often include exploration of design, evaluation and verification of design solution proposals, contribution to improvements/modifications to the design, and support for the validation of the developed design.
- ***Specifications***: The specifications constitute the description of what is to be analysed. Note that these specifications, derived from product specifications, are further elaborated and negotiated during the analysis task clarification.
- ***Level of concretisation***: The possibility of, and need for, establishing various levels of detail of computational model and result is highly influenced by the level of concretisation (or abstraction) of the design to be analysed, for which the available data and analysis purpose differ.
- ***Time***: A development project is based upon an often tight schedule. Analyses are connected to other project activities that depend on it or on which the design analysis activities themselves are dependent. Therefore a time constraint is often put onto the analysis task (not necessarily initially correlated to the time required by the task's purpose).
- ***Cost:*** As in every development project, cost is an ever-present factor that must be taken into account. Costs obviously put restraints on the extent of the task as well as on what is achievable.
- ***Process monitoring***: Continuous management, monitoring and communication to all relevant stakeholders throughout the activity allow for an adaptable process capable of handling imperative modifications to on-going tasks.

4.5 Example of influence of factors

The relationships both among the identified vital factors and with the design analysis process model are manifold. A couple of examples are selected to illustrate some common situations:

1. When a design analysis task is to be clarified (step 1), the product *specifications* should be formulated in design analysis terms, and the requested *level of concretisation* establishes guidance for selection of *knowledge* and *software* needed for analysis task execution (step 2). Furthermore, the selection of *software* and supporting *hardware* relates to the *cost* and *time* estimate requested by the product development project as well as the design analysis activity for setting the bounds of the execution. However, if an identified need requests knowledge or software not currently available within the enterprise, projects to establish this could be initiated or it could be acquired externally.
2. During design analysis execution, unexpected, overlooked or external *environmental issues* could emerge that have to be incorporated in the *specifications*; this could expand the purpose of the current task, redefine it or even trigger an additional design analysis activity.
3. Within the task completion of a design analysis activity (step 3), the level of information sent back to the project follows the description of the required outcome given in the *specifications*. The results assessment could also identify the need for improved development of V&V activities that can be formulated and implemented in the enterprise's *in-house tools (software)* and *procedures*.

5 DEALING WITH THESE FACTORS IN A DEVELOPMENT PROJECT

These factors affect the analysis activity more or less during all the steps of the design analysis process model. Nevertheless, they are best dealt with during the analysis task clarification activity (step 1). First, it is important to notice that, although this is quite absent from the literature, many analysis activities are planned already from the product planning phase. Product planning is the phase where time, costs, resources, and risks linked to the subsequent product development project are assessed. Such an early planning of design analyses happens for example in cases where the product-to-be is already relatively detailed (incremental product development), when the enterprise has a detailed QA

program, etc. This aspect is crucial, because during product planning *it is possible to act upon the factors at the enterprise level* (see Section 4.3) so that when the analysis starts these factors do no longer act as constraints. The analysis task clarification moment is then usually revisited (step 1') before task execution and completion in order to agree on any adjustment relevant to the prepared task (see Figure 2a). When the analysis task clarification directly precedes its execution and completion (Figure 2b), *it is no longer possible to act as widely at the enterprise level*. It is risky to change the hardware system on such short notice, new software needs customisation and employees require training, etc. It is still possible, however, *to act upon the project-related factors* (see Section 4.4).
This section 5 gives recommendations for what can be done during product planning and product development. The factors at the environment level (*regulations, standards…*) can hardly be dealt with during a development project. They must be taken into account outside a development activity. It is therefore outside the scope of this paper and will only be touched upon in the last part of this section.

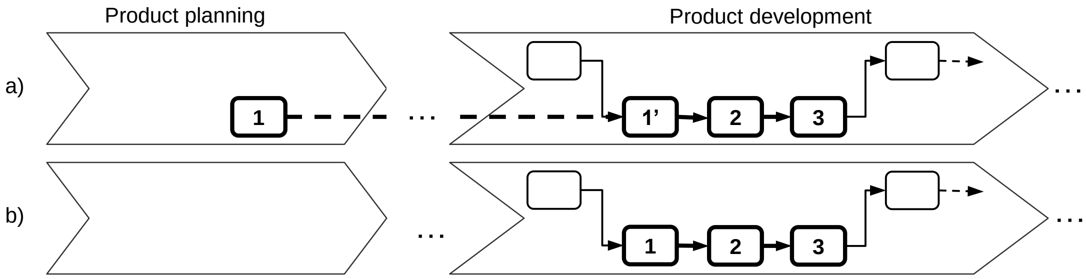

Figure 2. The analysis task clarification step (1) in product planning and product development. Steps (2) and (3) represent the analysis task execution and completion

5.1 In product planning

This section describes how the factors at the enterprise level (described in Section 4.3) can be handled. This has been organized as follows: for each factor, a typical question or a set of questions regarding how to deal with the factor that influences the analysis is asked, and some of the influences are listed. The user (analyst or design analysis organisation) can systematically apply these to a given design analysis task.

- ***Hardware***: What supporting hardware is suitable for analysing the identified design analysis activity? The lack of appropriate supporting hardware generally results in a need for investment in appropriate hardware environments; this in turn must be presented to the appropriate decision maker. Alternatively, the enterprise needs to cooperate externally to get access to the relevant hardware resources. It is possible during product planning to acquire the necessary hardware so that it is in place when the analysis is executed, whereas this is virtually impossible during product development.
- ***Software***: What type of software is in place at the time of the design analysis activity? When adequate software is not present, investment in commercial software or development of in-house tools must be decided already during product planning, because the negotiation for commercial licenses and the programming and V&V activities of in-house tools takes time, as well as training and development of routines and procedures. During product development, the possibilities are much more limited, and it may be necessary to outsource the analysis task.
- ***Procedures and stored knowledge***: What types of established procedures are in place at the time of design analysis activity? When procedures that are based on the common best knowledge as well as in-house expertise are not present, the description and development of appropriate procedures must be done a long time in advance.
- ***Organisation***: What supporting organisation is available at the time of design analysis activity? Organisations where the different engineering disciplines are located closely together offer a more intuitive environment for information exchange. The constitution of the desired organisation of the project team should be presented before the product development project gets underway.
- ***Employee competence***: What individual as well as combined competence level is available at the enterprise performing the design analysis activity? Inexperienced users need training and support from the enterprise. Note that another possibility is that experienced employees and experts (in-house or external) can serve as mentors for inexperienced colleagues throughout the duration of

design analysis activities, thus not only providing valuable support but also allowing for knowledge transfer to the inexperienced colleagues.
- ***QA assessment***: How is QA assessed in the enterprise such that confidence is gained for approaches used and results achieved? The current capabilities of the enterprise V&V methods should be appraised during product planning; it will be necessary to establish confidence. If current V&V methods are found to be inadequate, appropriate measures must be taken.

5.2 In product development

This section describes how the factors at the project level (described in Section 4.4) can be handled.

- ***Overall purpose***: What is the overall purpose of the design analysis task? The overall purpose should be weighed against the possibilities and limitations of currently available design analysis capabilities. If a discrepancy is found, it should be communicated in order to achieve an appropriate expectation regarding the outcome of the design analysis task.
- ***Specifications***: How to handle the specifications at the start of the analysis? The specifications should by no means be accepted "as is". The analyst might have limited knowledge about the design problem and need to discuss the relevance and accuracy of the specifications. (Petersson et al., 2012) discusses this aspect in greater detail.
- ***Level of concretisation***: At which level of product concretisation is the design analysis activity involved? The design analysis activity must be carried out based on the available data and information, and the corresponding output results should be presented accordingly.
- ***Time***: What time frame is set out for the design analysis task? The time frame should be selected such that it is efficiently connected to other project activities that are depending on it.
- ***Cost***: What cost frame is set out for the design analysis activity? Before committing to the design analysis tasks, the cost frame has to be carefully examined and mutually agreed upon among all involved stakeholders. Relevant cost frame is important, as it is correlated to the success rate of the design analysis tasks.
- ***Process monitoring***: How should process monitoring be carried out during the design analysis task? A well-planned process monitoring for all steps of the design analysis task is important for consistent, efficient and adaptable integration of the design analysis activity within the product development project. Thus, any new or updated information relevant to an on-going design analysis task should be communicated to relevant persons involved so that they have the possibility to act on and react to the impact that it might have on the design analysis task. Furthermore, if enterprise resources are modified at some stage of the design analysis process altering the initial time and cost frames, this should be conveyed to the project management so that adequate actions can be taken as soon as possible.

5.3 Outside of a development project

As mentioned above, the factors at the environment level (*regulations* and *standards*) can hardly be dealt with during a development project. If the enterprise wants to influence them, they need to take lobbying actions or participate actively in the development of those regulations and standards.

At the end of the project, another aspect of importance is that of capitalising the *knowledge* and *experience* acquired during the project. The endorsement from management on investment in resources and expertise knowledge for design analysis is vital (Adams, 2006). The *core competence of employees* performing the design analysis activities should continuously be addressed. The gained experiences and lessons learned through all design analysis activities should as far as practically and economically possible be elicited, formulated and stored as enterprise core competence for use in future projects (knowledge management). Without proper attention and control of employee competence and previous knowledge, the result could be erroneous decisions based on incorrectly established and evaluated computational models. Furthermore, it could lead to regression in effectiveness and competitiveness or even lack of trust in the design analysis activities if old errors are repeated.

6 DEALING WITH THESE FACTORS UNDER ALTERNATIVE ENTERPRISE CONFIGURATIONS

The in-house execution of design analysis activities at the developing enterprise (the company in charge of the development project) described in Figure 1 is the most unmitigated enterprise configuration, with full insight and control. Developing enterprises, however, do not always perform the analysis internally due to various reasons identified in the industry survey performed, such as lack of available resources and competences. Four additional enterprise configurations in which the design analysis activities are conducted have been identified. They are presented Section 6.1. Section 6.2 describes how to deal with the factors for each enterprise configuration.

6.1 Description of the alternative enterprise configurations

A first alternative enterprise configuration, displayed in Figure 3a, corresponds to the situation where resources for one or a selection of design analysis tasks are acquired externally (configuration a). The EC company merely provides the adequate resources for executing the tasks and the EC employee is assigned a workplace at the developing enterprise facilities utilising their resources. The EC company has the role of a staffing company. In the external execution configuration, displayed in Figure 3b, the design analysis activity is executed within facilities of the EC company with their available resources (configuration b). The communication and collaboration are primarily on a task level that aims at providing requested information on the project level. The enterprise configuration displayed in Figure 3c (configuration c) encompasses a broadening commitment in which the EC company and the developing enterprise have a closer and more in-depth cooperation, allowing for mutual understanding and commitments of investments in future demands on the design analysis activities. In this configuration the EC company is engaged to take full responsibility for the majority of (if not all) all design analysis activities within the developing enterprise. Finally, most products today are constructed of numerous more or less complex components and parts developed by various suppliers, as highlighted in the enterprise configuration displayed in Figure 3d (configuration d). These components need to be developed in parallel to the final product.

These different enterprise configurations are typical of common collaboration arrangements that are present in industry today. In practice, further decompositions into several layers of for instance suppliers, multiple external EC companies acting within a single development project and combinations of the configurations above are also common in industry.

6.2 How to deal with the factors for each enterprise configuration

Not all of the described enterprise configurations require their own design analysis process model or have specific factors. However, for each enterprise configuration, several of the described factors have different impacts in terms of organisation and effectiveness in planning, execution and arrangement of the analysis activity. The factors to specifically take into account for each enterprise configuration are discussed next.

In **configuration a** (external staffing analysis) *cost* and *employee competence* are the predominating factors in such an arrangement to take into account from the developing enterprise point of view. The *time* dedicated to the task, on the other hand, is a dominating factor from the EC company point of view in the sense that longer projects allow for reduced costs (due to less overheads). The analysis task execution in this form is more or less similar to the in-house configuration: the analyst works generally at the client's office, allowing for natural communication with the project team, which possibly improves the analyst's understanding of the product-to-be. On the other hand, the analyst can end up rather isolated, and does not benefit from the additional knowledge, competence and resources that reside at the EC company.

In **configuration b** (external outsourced analysis) the task identification and preparation of task mission (steps 1a and 1b) are often prepared within the developing enterprise and a request for a quote is sent for tendering to a selection of EC companies. Since the EC companies invited for tendering might not have insight into the developing enterprise's *standard procedures*, the task content brief needs to be expanded. The level of detail expected in the analysis results interpretation (cf. step 3a), *QA assessment*, etc. (that is, most of the factors at the project and enterprise level), needs to explicitly be included in the task content brief. Reaching a task agreement generally requires a questions and answers session about the task mission for each EC company retained, which requires increased resources and expands the *time* and *cost* frames during task clarification. The EC company executes the analysis tasks based on information provided by the developing enterprise as well as assigned *analyst competence* supported *by stored internal knowledge and developed procedures* originating from previous similar activities. These could also be beneficial for the developing enterprise since they might make use of these collective experiences gained outside their own enterprise. However, insights into the handling and control over their use are generally not controlled by the developing enterprise since it is proprietary information of the EC company, unless otherwise agreed. The developing enterprise does not necessarily need to have an organisation with competence suitable for task execution, but it should have an understanding of it so that the discussions around the task purpose and the specifications lead to a relevant analysis. An appropriate *process monitoring* must also be in place.

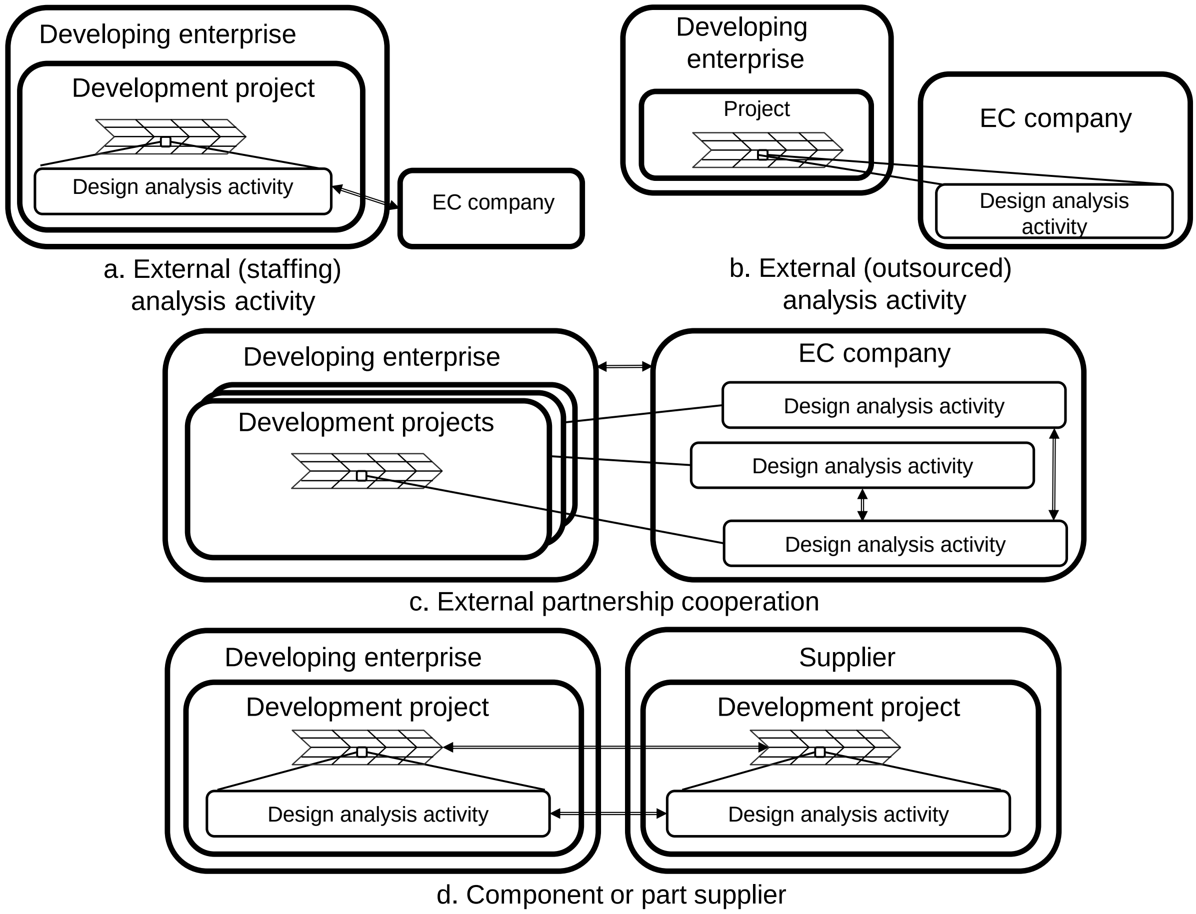

Figure 3. Types of alternative enterprise configurations

In **configuration c** (external partnership cooperation) many of the *enterprise factors* (*hardware*, *software*, *employee competence*, etc.) concern more or less only the EC company. The EC company is also more involved in the task clarification activity, providing the analyst's perspective on the task identification and task mission preparation (steps 1a and 1b). The *process monitoring* and coordination of design analysis activities within certain projects can be left to the EC company. The core competences from both companies can be utilised to establish a common *competence* and *knowledge* foundation, with regards to design analysis activities, that will make both companies effective and successful in their common product development endeavours. The nature of the design analysis activities can also be oriented towards methodology and technology development for future design analysis demands, resulting in additions to established *QA programs* and *procedures* of the developing enterprise. Since the commitment between the developing enterprise and the EC company is part of a long-term perspective, the project level factors connected with *cost* and *time* are not as central for each individual project as in configurations a and b, but should be considered in a more holistic perspective.

Configuration d (component or part supplier) is the most common configuration involving cooperation between developing companies. All documentation accompanying the delivery of the results (component or part) must be complete, self-explanatory and fully described, allowing unconditional approval from a *QA assessment* by the developing enterprise or by a third-party certifying agency. Essentially the companies perform two parallel projects (concurrent development of the whole product and of the component or part) that need continuous review and coordination on many levels. The enterprise factors affecting the operation at the supplier's side need to be adapted to comply both with the expectations of the developing enterprise and with its internal business strategy.

7 CONCLUSION

This paper has presented a set of factors impacting the design analysis task during a development project and how to handle them adequately. It has also taken into account the different enterprise configurations in which the activities take place. Being aware of those factors should prevent fastidious iterations because of a poorly planned and organised task. This work also shows that analysis cannot be considered as a black box in the engineering design process — a lot of interactions between the analyst and the engineering designer are necessary. It is recommended to systematically apply these guidelines to enable successful integration of design analysis activities into product development.

These factors are assumed to be present whatever the size and complexity of the project and the presented guidelines are therefore deemed relevant both for large companies and for SMEs, even if these guidelines can be completed for specific organisations.

It is very difficult, if not impossible, to determine whether the presented set of factors is comprehensive or not, but one needs to focus on factors that have greatest impact on design analysis. In future work, these factors will be tested in an industrial setup monitoring an EC company collaborating with developing enterprises through various enterprise configurations.

REFERENCES

Adams, V. (2006) *How to Manage Finite Element Analysis in the Design Process*. Glasgow: NAFEMS.

ASME (2006) *Guide for Verification and Validation in Computational Solid Mechanics*. New York, NY: ASME.

Bjärnemo, R., Burman, Å. and Anker, J. (1991) F.E.A in the engineering design process. In Dietrich, D. (ed.) *5th International ANSYS Conference and Exhibition*, Vol. III, Pittsburgh, PA, Swanson Analysis Systems, pp. 15.46-15.59.

Ciarelli, K. (1990) Integrated CAE system for military vehicle application. In Haug, E. (ed.) *16th Design Automation Conference - Concurrent Engineering of Mechanical Systems - DTC/DAC'90*, DE-Vol. 22, Chicago, IL, ASME, pp. 15-23.

Eriksson, M., Petersson, H., Bjärnemo, R. and Motte, D. (2013) A process model for enhanced integration between engineering design and computer based design analysis. To be published.

Goss, J. (1991) Selecting a FEA consultant. In Dietrich, D. (ed.) *5th International ANSYS Conference and Exhibition*, Vol. III, Pittsburgh, PA, Swanson Analysis Systems, pp. 15.37-15.45.

Hales, C. (1987) *Analysis of the Engineering Design Process in an Industrial Context*. PhD Thesis, Cambridge: Engineering Department, Cambridge University.

Hales, C. and Gooch, S. (2004) *Managing Engineering Design*. London: Springer.

Hubka, V. and Eder, W. (1996) *Design science - Introduction to the Needs, Scope and Organization of Engineering Design Knowledge*. Berlin: Springer.

King, G., Jones, R. and Simner, D. (2003) A good practice model for implementation of computer-aided engineering analysis in product development. *Journal of Engineering Design*, Vol. 14, No. 3, pp. 315-331.

Leahey, J. (2003) Strategies for implementing Finite Element Analysis (FEA) in design: Adopt, adapt and retain. In *NAFEMS World Congress 2003*, Orlando, FL, NAFEMS.

Motte, D., Eriksson, M., Petersson, H. and Bjärnemo, R. (2014) Integration of the computer-based design analysis activity in the engineering design process – A literature survey. Abstract submitted to TMCE.

Pahl, G., Beitz, W., (2007) *Engineering Design – A Systematic Approach*. London: Springer.

Petersson, H., Eriksson, M., Motte, D. and Bjärnemo, R. (2012) A process model for the design analysis clarification task. In Hansen, P.H.K., Rasmussen, J., Jørgensen, K. and Tollestrup, C. (eds) *9th International NordDesign Conference - NordDesign'12*, Aalborg, Denmark, Center for Industrial Production, Aalborg University, pp. 494-501.

Ulrich, K. and Eppinger, S. (2012) *Product Design and Development*. London: McGraw-Hill.