

Calculation Tool for Engineering

Samuli Lampinen

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| Abstract <p>The Study was conducted as qualitative research for K-S Konesuunnittelu Oy. The company provides mechanical engineering for technology suppliers in the Finnish export industries.</p> <p>The main objective was to study if the competitiveness of the case company could be improved using a self-made Calculation Tool (Excel Tool). The mission was to clarify processes in the case company to see the possibilities of Excel Tool and to compare it with other potential calculation applications. In addition, the mission was to build up and test a pilot-version of Excel Tool in the daily work.</p> <p>The research started with a theoretical approach by representing strategical preferences and studying the standards of engineering guidelines. After understanding the theory of the engineering process, engineering practices applied in the case company were outlined. Concurrently with the theoretical study, Excel calculator was developed and piloted in the daily work. The empirical approach also included the implementation of a survey and interviews with the colleagues. Calculation applications and existing spreadsheets in the markets were explored and compared against the intended Excel calculator. Personal experience was utilized in the study. Earlier studies of the subject were not found.</p> <p>It was realized that engineering process can be described exactly only in specific cases. The amount of calculation varies and the formulas needed depend on the product, which means that creating all-round Excel Tool will be practically an endless project. Excel Tool was still found reasonable for a small business avoiding risky investments. Excel Tool can improve the competitiveness of the case company when used in generic calculations with certain preconditions which were explicitly listed. Excel Tool is worth of developing in the case company. In order to utilize the results, an initial action plan was created.</p> | | |
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| <p>Tiivistelmä</p> <p>Työ tehtiin kvalitatiivisena tutkimuksena K-S Konesuunnittelu Oy:lle. Yritys toimittaa mekaniikkasuunnittelua vientiteollisuuden järjestelmätoimittajille.</p> <p>Päätavoite oli tutkia, voidaanko kohdeyrityksen kilpailukykyä parantaa itsetehdyn Excel-laskentatyökalun avulla. Pyrittiin selvittämään suunnitteluprosessin kulku kohdeyrityksessä Excel-laskimen mahdollisuuksien hahmottamiseksi ja sen vertaamiseksi muihin potentiaalsiin laskentasovelluksiin. Tavoite oli myös laatia pilot-versio Excel-työkalusta (Excel-laskimesta) testattavaksi työn ohessa.</p> <p>Työ aloitettiin teoreettisella osuudella kuvaamalla yrityksen strategiavalinnat ja perehtymällä suunnitteluprosessien standardeihin. Yleisen suunnitteluprosessin hahmotuttua, laadittiin prosessikaavio kuvaamaan kohdeyrityksessä harjoitettuja työvaiheita. Teoriaosuuden rinnalla Excel-työkalua kehitettiin ja pilotoitiin päivätyön yhteydessä. Empiirinen osuus sisälsi myös kyselytutkimuksen toteutuksen ja kollegoiden haastattelua. Markkinoilla olevia laskentasovelluksia ja valmiita Excel-laskupohjia etsittiin ja verrattiin aiottuun Excel-työkaluun. Oma kokemusta hyödynnettiin tutkimuksessa. Aiempia tutkimuksia aiheesta ei löydetty.</p> <p>Ymmärrettiin, että suunnitteluprosessi voidaan kuvata vain yksittäisessä tapauksessa. Laskennan määrä vaihtelee ja käytettävät kaavat riippuvat tuotteesta, joten laaja-alainen Excel-työkalu olisi käytännössä loputon projekti. Excel-työkalu havaittiin kuitenkin järkeväksi riskipitoisia investointeja välttävälle pienyritykselle. Excel-työkalu voi parantaa kohdeyrityksen kilpailukykyä yleisluontoisissa laskutoimituksissa tietyillä reunaehdoilla joista laadittiin lista. Excel-työkalua kannattaa kehittää kohdeyrityksessä. Työn tuloksien hyödyntämiseksi laadittiin jatkosuunnitelma.</p> | | |
| Avainsanat (asiasanat) Excel-Työkalu, Excel-laskin, Mekaniikkasuunnittelu, Lisäarvo, Pienyritys, Alihankintasuunnittelu, Lean-johtaminen, Diversifikaatio | | |
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1 Addressing global challenges

Shifting the production of the western industrial countries to low-cost countries, so called the China-phenomenon, has also effected the Finnish technology industries. For many years, the news and public debate have dealt with reductions in labor force and relocating production and outsourcing the supply chains. These changes have not had as strong an influence on engineering as on the production, but engineering may be next victim of the trend. For the Finnish technology suppliers, the economic competitiveness has been seen as a weak point. As the engineering costs have increased in relation to production costs, domestic subcontractors in engineering should take measures to prevent losing their part.

To develop the engineering processes and to maintain their competitive edge, strategic planning was initiated at K-S Konesuunnittelu Oy in 2013. This study is part of the planning, and is made as a qualitative research for the company. K-S Konesuunnittelu produces mechanical engineering for customers in the Finnish technology industries. The author works as the owner in the company and has no partners or employees at the moment.

The author has considered how to ensure the success in the markets, if the technology suppliers start to outsource their mechanical engineering into low cost countries in the future. So far, the demand for domestic engineering entrepreneurs has been adequate, except during the sharpest downturns.

The author has an objective to maintain the competitiveness but also to grow the business in the future by either increasing personnel or even expanding the business from engineering to their own engineered products. In order to expand the business into new areas, versatile activity is needed to find new possibilities. The improvement of current processes and search for new opportunities were considered the main cornerstones of the strategy for the coming years.

During the unsteady times in industry since 2008, the author has had the possibility to work and study simultaneously, which has enabled instant appliance of new knowledge in practice. Studies of marketing strategies and Lean management have

affected the thinking process and the author has been contemplating if the concept of Customer Value could be a solution to these global challenges.

Besides the theoretical consideration, the author has experienced time waste in the daily work calculating operations which are in most cases repeated several times during a design process. Engineering calculations can be performed in several ways, but being available for a basic engineer – not only a statistician - Microsoft Excel has proved to be an obvious choice. Because Excel has some drawbacks in complex calculations limiting its potential, the author has reflected on the possibility to optimize Excel usage onto a new level. The idea of a self-made *Excel calculator* was born and was considered also as a subject of this thesis. In order to verify that the idea is suitable for adding *Customer Value*, the subject turned into a research covering both the theoretical and empirical approaches.

1.1 Objectives

The main objective of the research is to study if the competitiveness of the case company can be improved using a self-made Excel calculator. Also, reaching a better understanding of the conducted processes is pursued.

The aim is to clarify processes in the case company to see the possibilities of *Excel Tool* (Excel calculator) and to compare it to other applications. For empirical aspects, the objective is also to create a pilot-version of Excel Tool to be tested in the daily work.

The minimum objective is to achieve any new information about the company, its strategy position, customer value aspects, processes exercised and to produce knowledge of calculation solutions.

The research may be regarded as a preliminary study approaching the problem from several point of views, which are described with the missions in the chapter 3.1.

2 Calculation

The author has been working for 15 years in mechanical engineering in many companies for numerous projects. A typical engineering task has contained multi-

staged calculations which have been resolved quicker by compiling the formulas into an Excel spreadsheet than using a traditional method of a paper, pen and calculator. As we know, Microsoft Office Excel offers many ways to manage data, allowing user also to build up formulas into cells. Because of that flexibility, Excel is widely used in the academic and economic life.

Also in the case company, Excel is significantly utilized in calculation. In past years, using Microsoft Excel has become familiar and many formulas (i.e. calculations) have been created by the author.

However, it has been challenging to reuse a pre-made Excel formula later on. When it has been sketched fast for a specific case and one-time need, the formula has been forgotten and unclear the next time. Especially for other users, it has appeared difficult to understand what the formula contains, where it is applicable and where it is not. Also, the appearance and behaving logic of an Excel sheet changes depending on the day and the creator. Extra time is also spent on looking for possible pre-made Excel files. For said reasons, it is faster to compile a new Excel calculation every time than try to find and understand any existing one.

2.1 Idea of a Centralized Excel calculator

Rebuilding Excel-formulas (equations) was seen as a *Non-Value Adding Process* realising every time the rebuilding was repeated. From that background of experience and theory of Lean, the author generated an idea of a centralized and uniform Excel Tool.

The author has not faced in any company that kind of centralized Excel Tool but separate Excel-files in multiple locations in users PC's and work place's network. Additionally, calculations are also carried out by numerous and redundant applications, not just by Excel.

Author has seen constant searching and recalling for engineering equations from database and books time-consuming and worthless use of mental resources. Based also on conversations with several colleagues during past years, the author was convinced of need for such tool. Practical utilization was main criterion also in selecting the subject for the thesis.

In choosing the topic for the thesis in beginning 2016, it was essential the subject would help K-S Konesuunnittelu Oy some way in mechanical engineering. Author has had for long time an idea of a practical tool to optimize every-day engineering by offering basic calculations and data in a centralized Excel Tool. This tool could mean just one large Excel-file or a main Excel-file directing by links to other design sections. Later on, this Excel Tool could be extended by adding new calculations and data to make Excel Tool wider or just modificate it to correspond work for a certain customer or in specific field of mechanical engineering.

The idea of the tool was presented at a current customer by the author. The customer showed interest to the tool and was willing to participate in making it.

From the beginning, it was decided to compile Excel Tool in Finnish, for to decrease it's value in foreign markets.

When planning this study, the original objective was just to build up a uniform and centralized Excel calculator to speed up the daily engineering work. Later, the idea was understood too uncertain, basing only to personal experience and visions. For that reason, the planned project was changed to a throughout research. Just building up Excel Tool without a research could have been a step to the wrong direction.

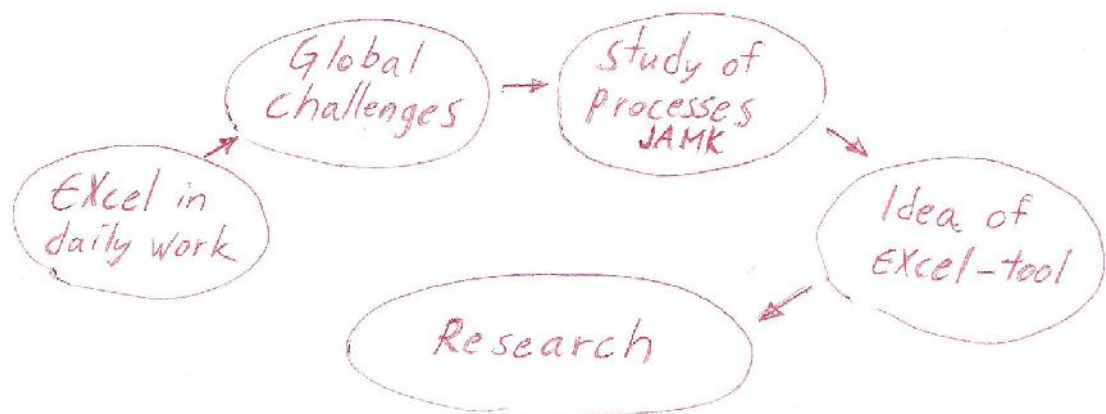


Figure 1. Research from personal point of view

3 Research overview

Due to the global challenges, measures were to be taken to hold position in the markets. Since the subject of *Added Value* was understood during the education, adaptability of it in the daily work was considered. Finally, the idea of an enhanced Excel calculator was shaped.

At this point, two principles of using Excel must be separated: Firstly, making tabulated datasheets and summarize-lists and secondly, building up calculators by typing equations into the cells. This research concentrates on the latter one, but utilizes also Excel's database benefits.

Quality is excluded as a way to competitiveness. Even if *Value* is comprised of *Price* and *Quality* (MacDivitt and Wilkinson 2012, 31), quality will be now assumed stationary, in order to have other factors comparable. The exclusion does not mean underestimating quality. Conversely, it is judged and boosted all the time but apart this research.

There are several earlier studies of specific Excel calculators, but no study was found of using Excel as a primary calculation tool generally in Mechanical engineering.

The research is quite abstract as engineering itself, but it tries to answer to the next questions:

-Is it possible to improve the competitiveness in the case company by an Excel based calculation tool?

-Are there any existing tools or cost-effective applications in the markets?

-What are the factors underlying the results?

This qualitative research bases both on theoretical and empirical research methods. The theoretical part of the research addresses Value based pricing, Lean management, general engineering guidelines, survey methodology and seeking for information of calculation solutions. The empiric part concerns the personal experience, investigation of applied processes and operations, interaction with colleagues, executing a survey and practical discoveries during Excel-use and build-up. Theory and empiricism are mixed when they meet.

3.1 Three approaches

The problem was concurrently investigated from three point of views for a comprehensive understanding. It was estimated, that any of the approaches may produce such information which could effect on or exclude the others.

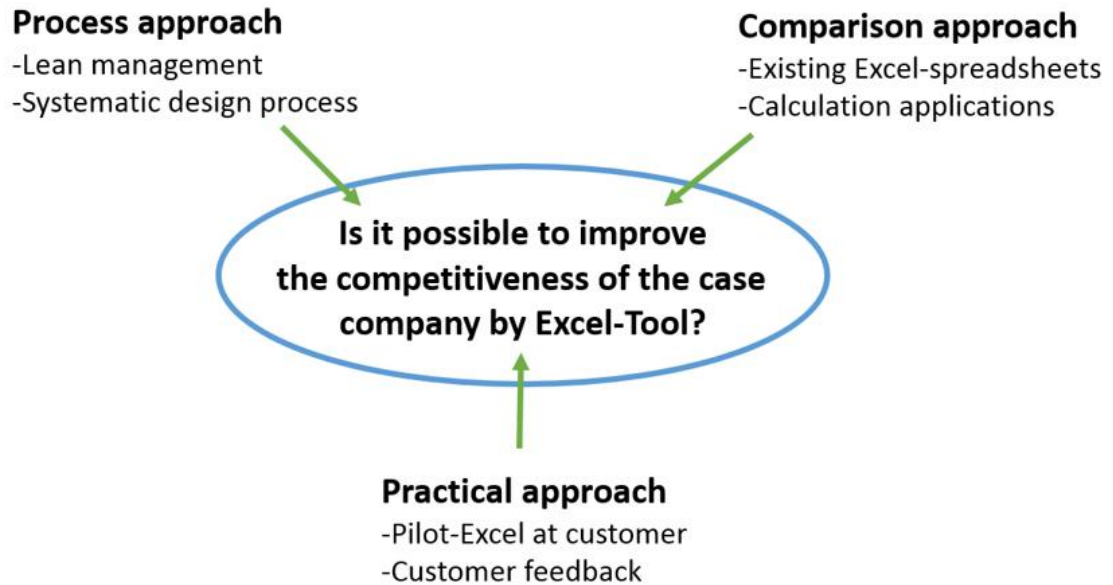


Figure 2. The problem and three approaches

3.1.1 The process approach

The process point of view utilizes the existing theories of Lean management and general design guidelines VDI 2221 and VDI 2222. By means of the theories and experienced engineering procedures, the process flow in the case company will be illustrated as accurately as possible in order to understand the factors beyond the design process. After the case processes have been mapped, the significance of the calculation process will be evaluated. The processes are estimated also to see if calculation could be some way obviated, for example by team work at the customer etc.

3.1.2 The comparison approach

Applications and existing spreadsheets in the markets will be explored and evaluated against the intended Excel calculator. Data will be collected from the internet and analyzed on the grounds of internet articles but also of the personal experience. Also a

survey and interviews will be performed to produce information of alternative and preferred solutions.

3.1.3 The practical approach

Concurrently, the Excel calculator will be developed and piloted in the daily work in order to get empirical aspects on the subject. The survey on colleagues is wished to produce new ideas and opinions of preferred features for the calculator.

3.2 Analyzing the data

All the three approaches analyze the data comprehensively according to the qualitative research methods and no numerical data is processed. In addition, personal experience is used to evaluate the processes in the case company. Reader is advised to consider whether the results apply in his case.

4 Strategy and competitiveness

4.1 The strategy decisions

In order to establish the main objective, the fundamental strategical preferences of the case company must be described. The formation of Customer Value will be also explained as a key to competitiveness.

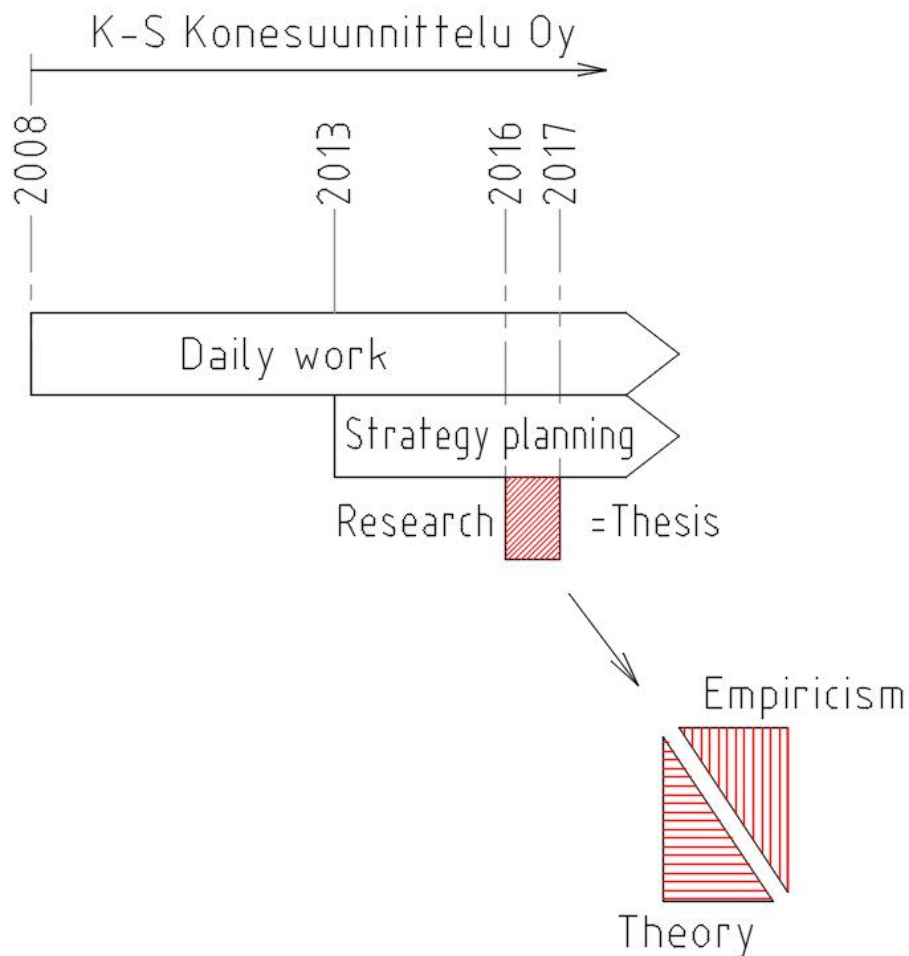


Figure 3. The research from a company point of view

Strategic management is a conceptual and wide discipline having several approaches and a long history starting from Sun Tzu's "Art of War" and "On War" by Von Clausewitz, leading to Business strategy originated in the 1960s. Strategic business management can be roughly outlined as defining the goals, initiatives, measures, plans, prediction, scenarios and resources for the coming years. Strategy can be described as a

planned direction for a company for the next 3-10 years. If the strategic planning is omitted, there is a risk of drifting. (Strategic management 2016; Vesiluoma 2013, 7.)

Yet strategic planning is important, in a rapidly evolving environment it is hard to predict a singular scenario on which to build the strategy. It is more appropriate to map several scenarios and paths leading to them. (Vesiluoma 2013, 7.)

During the strategic planning of the case company, the author explored the book "Strategy Safari" and adopted the importance of learning and thinks that by departing the path there comes opportunities to find new things (Mintzberg, Ahlstrand & Lampel 2009). By only repeating the earlier actions and forming a strategy by putting all it on the paper, the business will be fixed and inflexible. Even if you were happy with your specific product, it should still be developed to be competitive also in the future.

In order to find new possibilities in a business, Mintzberg and colleagues (2009, 215) stress the importance of *learning*. They have described by Honda's example, that acting and trying new things can generate new business ideas or ways to implement the existing ones, being resulted even accidentally (ibid. 2009, 215).

The statement is not however, that writing a strategy plan is pointless, but essential is to understand, that structuring a business can precede the formal planning as well. Mintzberg and others (2009, 37) have symbolized it: "Structure follows strategy ... as the left foot follows the right." The sentence puts to think, if a company's structure should rather go side by side with its strategy, both taking their turns and supporting the company.

The case company has experienced the domestic markets quite thin for the sub-contracted engineering. Specializing into a singular product means often relying on a singular customer. Being the best partner and having the latest and deepest information of a certain product does not help you, when your customer is the last local manufacturer of it and for some reason finishes its business.

Stan Mack, a business writer, whose articles has been published in online editions of e.g. Houston Chronicle and USA Today, explains that *product specialization strategy*

often chosen by a small business, may cause a risk due to sudden changes in the narrow markets. The product specialization strategy may also prevent from seeing new possibilities. (Mack n.d.).

The aspects of *Diversification* and continuous learning were taken into account during the strategic planning and a decision was made: In order to avoid the risks and to find new possibilities, the company's business will rather be versatile, adaptive and flexible than specialized in a certain type of mechanical engineering.

In addition to looking for new opportunities, the present operations should be developed and streamlined to be competitive in facing the global challenges.

The other way around, an aspiration is to secure the competitive edge in the existing business activity by streamlining the engineering processes, but not to the detriment of strategic learning.

4.2 Customer value

Due to the one-man organisation and a straightforward character of subcontracted engineering, it is easy to understand the key elements of the competitiveness. What a customer (cf. a Finnish technology supplier) basically wants, are the results of the engineering assignment, but not the time used to generate them. That is concluded in the case company, since 2010 requests for fixed price quotations have increased. Also the risen pressure in the hour work has indicated the trend to cut off idling.

Customer's tend to minimize the engineering costs either by outsourcing to low cost countries or by decreasing engineering time in Finland are both linear and direct measures to maintain their competitiveness. However, such measures include risks of ending up in a lower quality and savings in the direct costs may mean a later loss in the project and the fall in a reputation. Such incautious cutting of engineering time is not desirable either from the subcontractor's point of view; providing lower quality for a customer has effect also on a supplier's reputation.

At this point, we must remind that the customer makes the decisions in purchasing, regardless they are right or wrong. The customer decides the budget and estimates

which suppliers offer the best value for his money. A supplier can win the bidding by offering more value. (MacDivitt and Wilkinson 2012, 11-12.)

MacDivitt and Wilkinson have developed *Value Triad* to depict customers' three approaches in decision making: Cost reduction, Revenue gains and Emotional contribution. (ibid., 13.) The first two of them are dominant in business to business (ibid., 16).

MacDivitt and Wilkinson further represent value maps with *Customer Value Line* (CVL) to illustrate the relationship between Price and Quality. Quality is at x-axis, Price at y-axis, CVL being linear between them. (ibid. 28-31.) For a supplier it is most reasonable to operate near the CVL, where the pricing and quality are in balance (ibid. 32-33). Depending the location along the line, a supplier is regarded low cost supplier or premium quality supplier (ibid. 30-31). Principle of MacDivitt's and Wilkinson's value map was used to depict the threat of the rising quality level of foreign competitors.

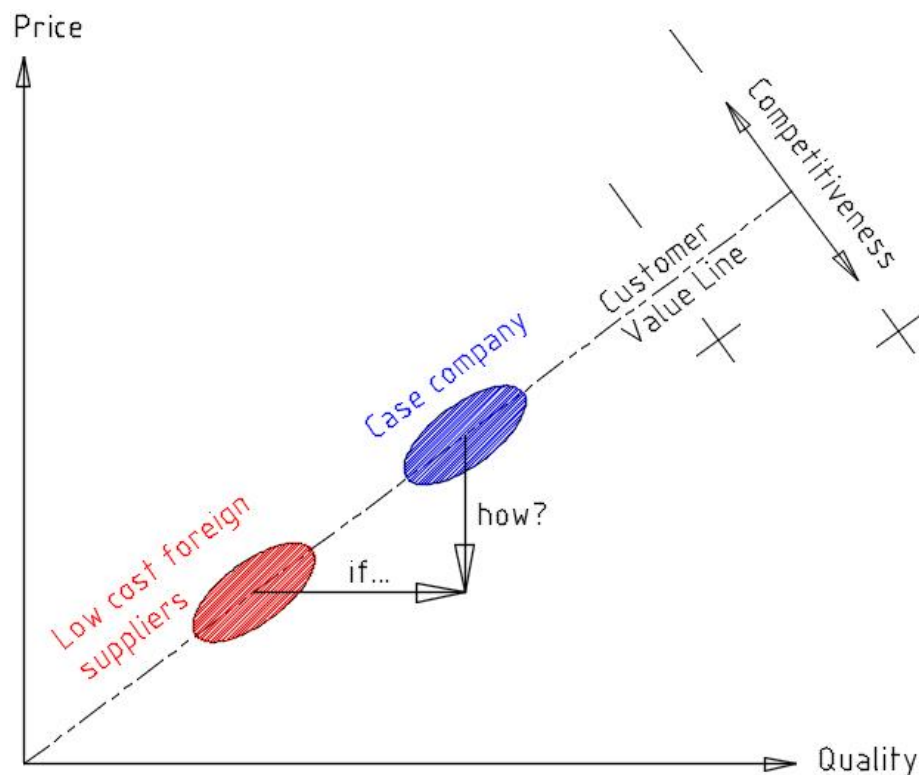


Figure 4. Customer Value Line (MacDivitt and Wilkinson, 31.)

If we consider, that the inexpensive labor force transfers production into Asia, what is needed for the rest, the products and engineering follow after?

Moreover, it is not so much western enterprises to blame for the advance in Asia. The voluminous population and the markets of Asia are actual reasons for the progress, which has already started: The revenue and the profit of listed engineering companies in Pacific Asia begun to grow far before the financial crisis and will grow more in the future because of urbanization and the demand for a greater infrastructure. Also many great western companies have already located their engineering in the area. All that development has lifted knowhow and quality onto a new level where it can further breed, forming skilled engineering and business ecosystems. (Asia Rising 2014.) In the author's opinion, quality means also an ability to take responsibility for a greater part of the customer's value chain, possibly providing of ultimate turn-key services which include everything between project engineering and local commissioning.

As described, the key elements to define the value are the price and the quality. The question is, how to add customer value without decreasing own profit? As stated, Quality-adding is not addressed in the research and will be developed separately, so we concentrate on Price.

Price means naturally the charge for an engineering assignment, which can base on a fixed deal contract or be formed of an hour charge multiplied by time. If time equals but price is decreased, the profitability will decrease as well, which is not advisable. The answer for the question may be found in management systems like Lean.

4.3 How to add Value by Price

Lean management is developed in Japan on the grounds of Toyota's production principles (Kouri 2010, 6). Lean management emphasizes a customer orientated approach and generating value for a customer. Essential is to recognize the processes of the production and to divide them into *Value Adding* and *Non-Value Adding* categories. By concentrating on the Value Adding processes and removing the Non-Value Adding processes, the production and that way the competitive advantage of the company will be improved. (ibid., 6-8.)

The author has considered if the same principles and rules would cover also engineering, being regarded as a form of production. Searching for redundant processes and decreasing engineering time without losing the quality might be the key for improvement. What was educated about processes during the bachelor studies in production and technology, was now adapted to the engineering processes. Since the lessons, the author has constantly considered and estimated his personal engineering processes on the grounds of Lean. In the next chapters, the theory of the design process is described. Pay attention, that the process charts shown correspond with *Value Stream Map* of Lean (Martin 2014, 223).

5 Engineering process

5.1 The theory of design process

Designing, later referred to as *engineering* or *designing*, is a creative process where ideas and alternatives are reasoned and compared against each other for to find the best combination of features to satisfy the *requirements*. The process is very iterative where the same steps are repeated on always higher and higher information level.

According to Pahl and Beitz (1976, 1) an engineer's fundamental mission is to find solutions to technical problems and to solve them using the best practice between the limitations in each case. Pahl and Beitz define the constructing as realization of thinking which tries to fulfill the requirements set with the best and latest means. (1.)

Yet engineering or designing can be seen as a form of art, systematic procedures have been developed to make engineering more understandable and teachable. The history of written guidelines for designing and inventions starts with Kesselring's book "Technische Kompositionslehre" in 1954. In the book Kesselring introduces *Guideline for Inventions* containing his self-experienced designing methods and practices. The second guideline for engineering was proposed by Hansen in 1965. Hansen emphasizes logical sequences in designing and regularities between the task and solutions.

In 1973 these predecessors Kesselring and Hansen with several professors generated Guideline VDI 2222 *Design engineering methodics Conceptioning of industrial*

products. Essential idea in VDI 2222 was dividing the design process into four distinct phases. (Jänsch & Birkhofer, 47-48.)

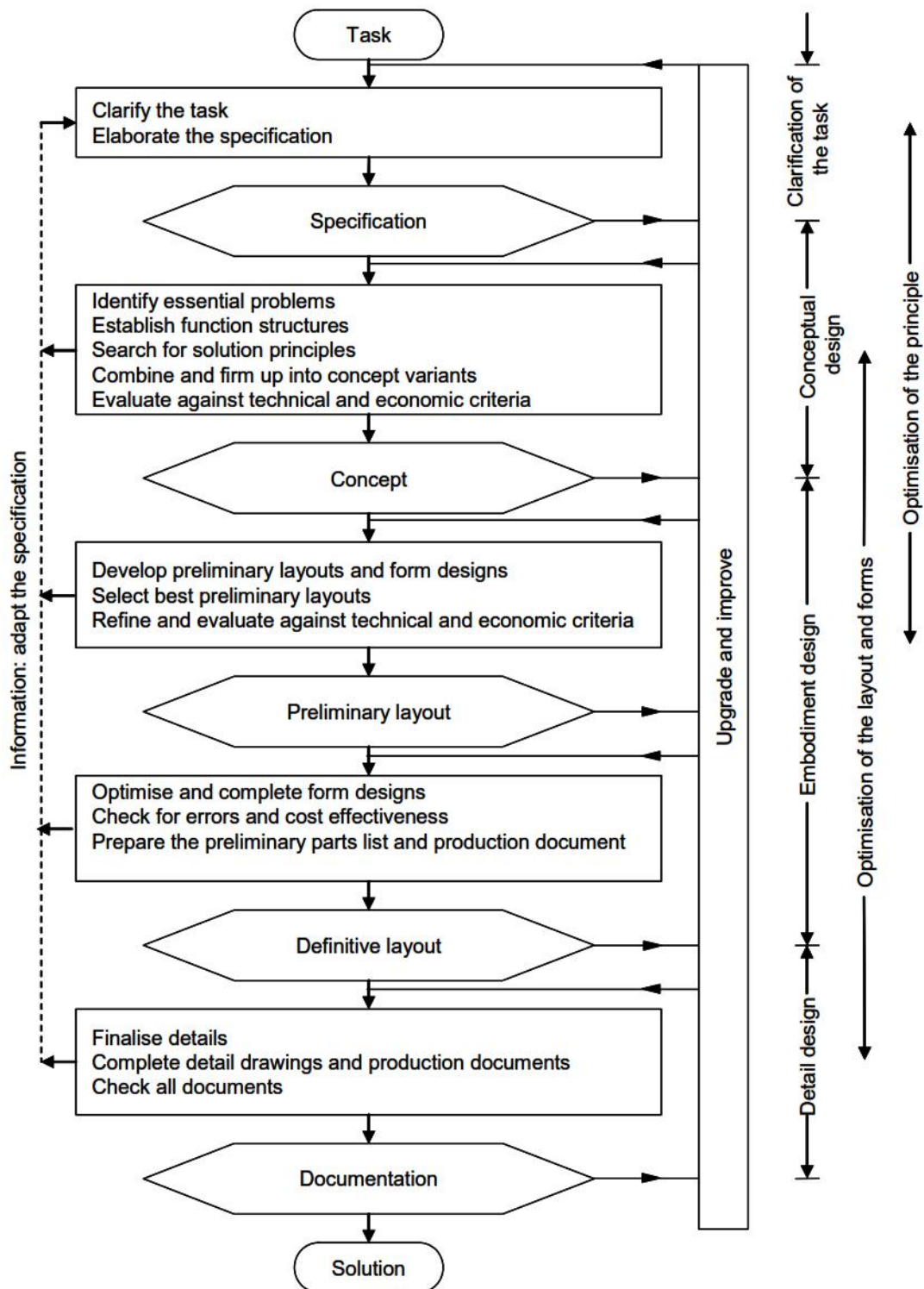


Figure 5. VDI 2222 (Jänsch & Birkhofer, 48.)

In 1993, VDI 2222 was replaced by VDI 2221. The newer guideline bases on the previous one, but has more organizational approach and represents designing in more universal context by highlighting methodical designing of whole systems. VDI 2221 also points out iterative design cycles conducted by requirement lists throughout the whole process. One significant reason for publishing VDI 2222 was the arrival of computer aided drafting, CAD. (ibid., 49.)

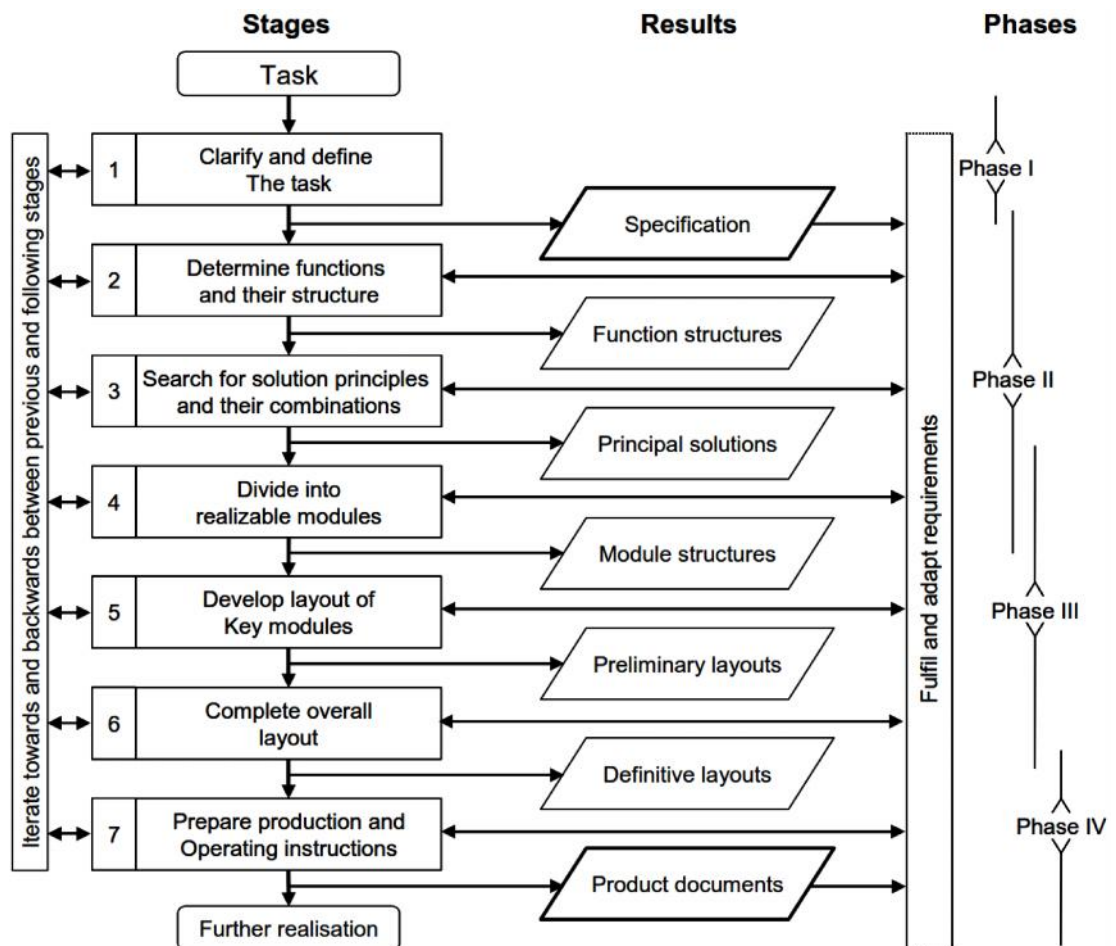


Figure 6. VDI 2221 (Jänsch & Birkhofer, 49.)

5.2 Appliance of the design guidelines

Because the theory can not fully describe real practises in all companies, it was seen important to customize the chart to reflect the design process in K-S Konesuunnittelu Oy. It was necessary to understand what happens during designing in the company, in order to evaluate the calculation process and Excel Tool in it.

While VDI 2221 contains also the four main design phases as the earlier guideline, content in the newer one seems to address more the whole layout than designing of single modules and their details. The author sees, that the newer guideline approaches the subject more abstractly whereas the previous guideline has more stress on concretic things, like module structures. On that account, the earlier guideline VDI 2222 reflects better the process that is performed in K-S Konesuunnittelu Oy or any company providing subcontracted mechanical engineering. However, the author thinks that there is one essential element missing in the earlier guideline: Requirements for the design. The requirements play an important role in the third phase, in embodiment design. Embodiment design means practical engineering, where *iterative actions* are performed and must be proved that solution satisfies the requirements.

The fourth phase, detail design has similarities with embodiment design, the difference is just the level of design. When embodiment design addresses layouts and modules, the detail design treats subassemblies and parts of modules. Detail design must not be underestimated as it may bring up a problem of manufacturability of a single part.

Design process can be partitioned into two according to the executor. Typically a design is started by the customer or an end customer. VDI 2222 was outlined into two sections to show an approximate interface between the customer and the subcontractor.

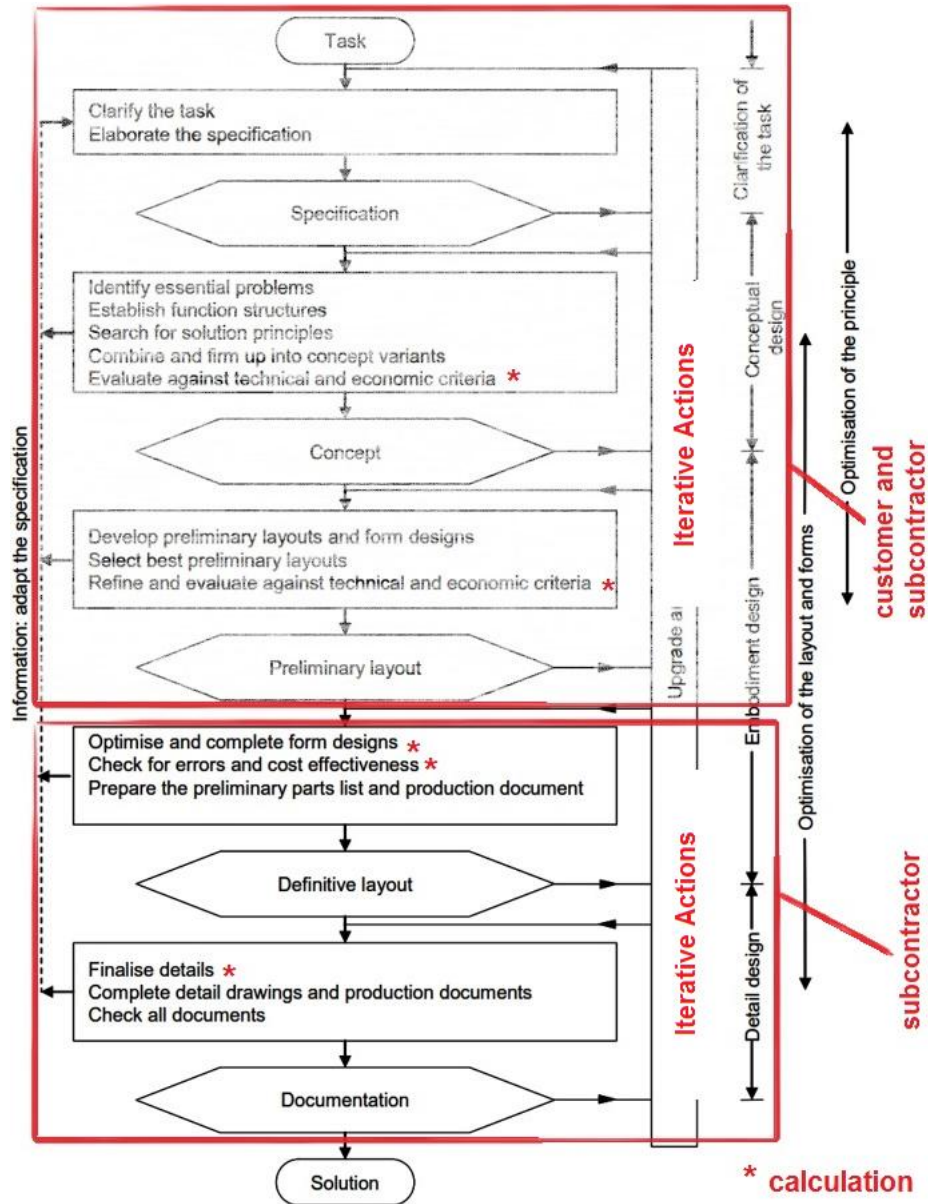


Figure 7. Modification of VDI 2222 for the case study (Jänsch & Birkhofer, 49.)

5.3 Value Stream Map of K-S Konesuunnittelu

Please note, that evaluation of the case processes in the next chapters pertain to empiric part of the study. There is no valid former theory of the case company, actually this study tries to create a one. However, evaluations base on the theories above and the reader is advised to reflect on applicability of the statements in his case.

The previous chart was still not clear enough for the purposes having needless items and blurry interfaces between responsibilities. After the theory of design guidelines was studied and the real practises understood, a company-specific flow chart was created to mirror essential steps and the engineering process in K-S Konesuunnittelu. As mentioned above, Guideline of VDI corresponds to Value Stream Map in Lean management, which describes the value stream in the production. Value Stream Map depicts the big picture from an order input to release. There may be several Value Streams between Enterprises involved. (Martin 2014, 22; 223-224).

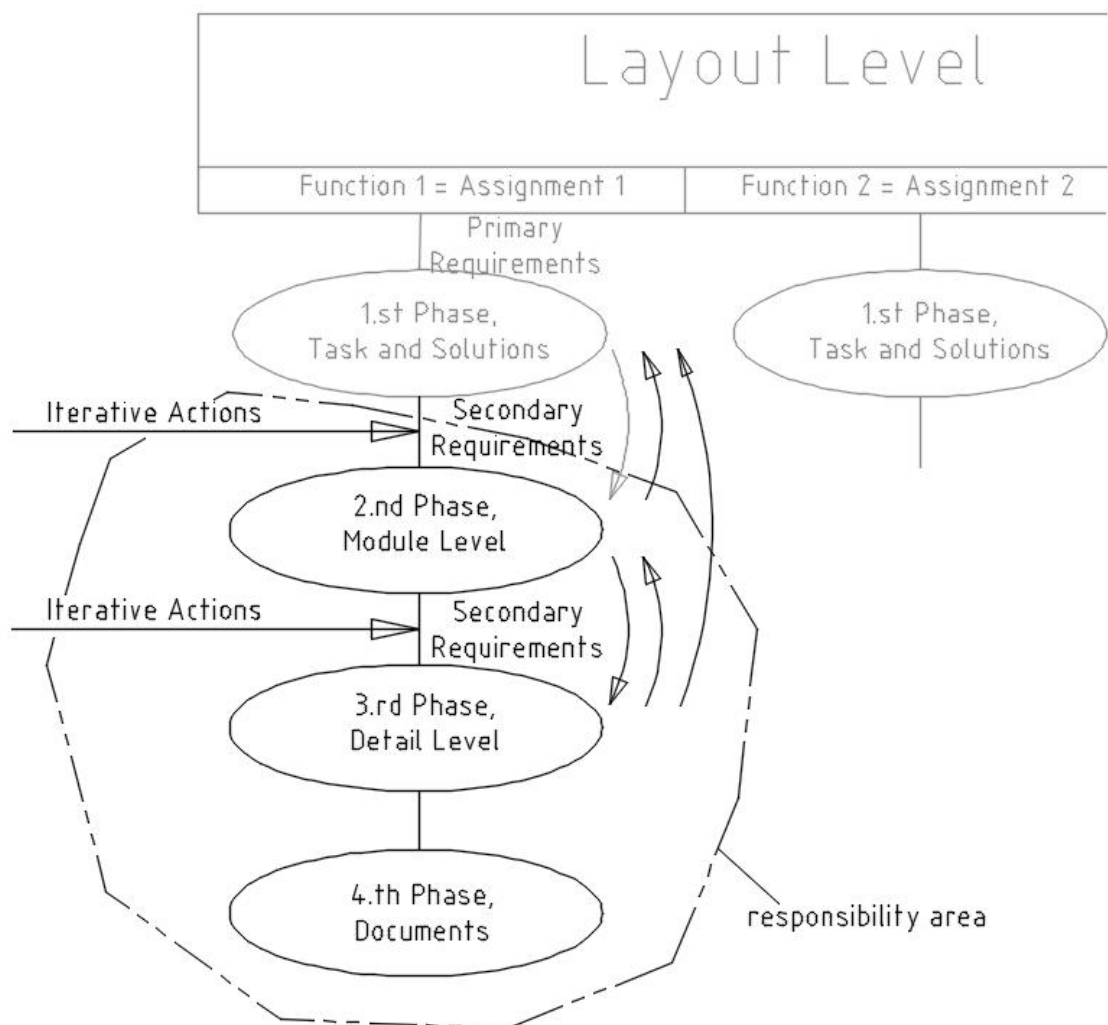


Figure 8. The value stream map of K-S konesuunnittelu

The case company's map is reduced by highlighting only the responsibility areas. Layout-level items are shown just as informative. The first phase is also faded out from the map. Conceptual design and preliminary layouts indicated in the VDI-guidelines are included in the previous items, therefore the terms are not seen in the map.

New terms represented for the case design process are *Primary requirements* and *Secondary requirements*. Even if the "Requirements" were issued in VDI 2222, the abstract was now divided based on differences between the upper and the lower level requirements. Primary- and Secondary requirements are described in the next chapters. Also a new term *Iterative Actions* was represented and is explained below.

5.3.1 Phase 1

Primary requirements are the necessary functions which a design is expected to perform (e.g. transfer a product). At the brainstorming stage, ideas of implementations are creatively and spontaneously contributed. That work is typically performed by the customer, resulting a technical specification which is a starting point for the subcontractor.

5.3.2 Phase 2 and 3

Secondary requirements are applied first at the second phase of engineering where a particular implementation is evaluated. Secondary requirements are such as limitations set by a budget, the customer, producibility, space reservation, force, takt time, environmental conditions, expectations of a life time, rigidity and safety. Most of the secondary requirements are connected straightly to physics and calculated with a pen, a calculator or a PC's software. Requirements can apply to geometrical features considering the shape, size, trajectories or similar features of a specific part or an assembly. Requirements are related also to such physical quantities as work, force, energy, pressure, speed, temperature etc. If the requirements are not met, the implementation must be changed and the phase restarted. Changing the implementation needs customer's approval and this is the interface between the responsibilities.

When the second phase is completed, the design proceeds to the third phase, detail engineering. Detail engineering has similar processes and faces also the secondary requirements like the second phase, just dealing rather with single parts or sub-assemblies whereas the second phase addresses the whole device. Changing parameters at the third phase may mean e.g. changing a single component, dimension, function or modifying an operation scheme, still maintaining the implementation unchanged.

Practically, the second and third phases are processed more or less concurrently as the interface between them is not clear. Shortly, if an implementation decided by the customer fails during second and third phases, the next implementation will be evaluated which means restarting the phases.

Iterative Actions represent the major part of the work during the phases two and three. Iterative Actions concern subcontractor's work to realise the given idea of an implementation to a detailed design structure. Practically, Iterative Actions consist of evaluation and calculation operations to check the secondary requirements and changing of parameters when needed.

A design consist often dozens of parts which all have several parameters like size, material, geometrical features, feature dimensions, manufacturing methods etc. It results thousands of variations for the design. Even if all the variation are not relevant to be calculated, there are still numerous dependencies impacting on the end result and several iterative actions must be performed. Simple example: increasing the size of a gear motor in a wagon for better acceleration results a bigger drive shaft in diameter, leading onwards to bigger shaft bearings and a heavier framework. After all the components are defined, the mass of the wagon has increased. The new acceleration of the wagon must be calculated using the new mass. It will be time consuming to make iterative calculations in stages by a pocket calculator.

Changing a single parameter in a design can affect on the other parameters so that the calculations must be restarted for the assembly but also for some of the parts. In the wagon case, in addition to calculating the acceleration of the wagon, it may be reasonable to check strength of the wheel hub after enlarging the shaft.

Moreover, the same calculations may be repeated several times during a single engineering assignment, always when something relevant changes.

5.3.3 Phase 4

After the second and third phases are successfully passed, it is time to generate drawings and part list into the customer's product data management system.

Documentation work bases fully on the customer's CAD- and PDM-systems and there are no possibilities to develop it faster without developing the systems themselves, which is out of reach for a subcontractor. Of course, the systems can be used more or less efficiently, and continual improvement of the documentation process is also constantly addressed but apart from this study.

5.4 Operations in K-S Konesuunnittelu

It was concluded above, that the case company starts work in the phases two and three, and finishes it with documentating in the phase four. The phases two and three form the major part of the company's assignment and the phase four is excluded from this research.

The term *Iterative Actions* was created to describe the work performed in the phases two and three. The work consist of two types of *Value Flows*: *Solution-checking* and *Parameter-changing*. By the terms of Lean, Value Flow is a sub-category of Value Stream (Martin 2014, 223). Figure 9 shows the partitions of the two Value Flows in an example case of engineering assignment.

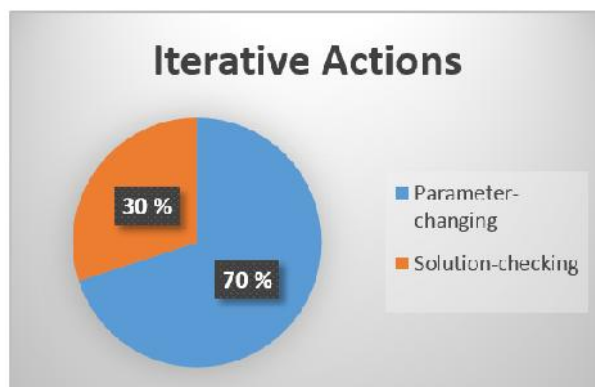


Figure 9. Distribution of *Iterative Actions*, a term issued by the author

Parameter-changing relates to studying and searching for components and to the modelling procedures performed in a CAD-software.

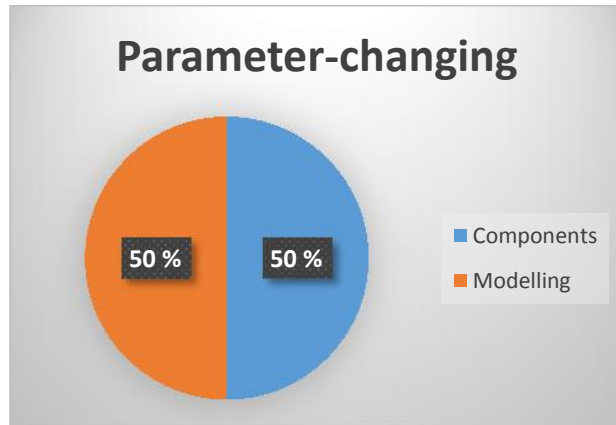


Figure 10. Distribution of *Parameter-changing*, a term issued by the author

Solution-checking is divided into qualitative and numerical actions, the first one is formed of evaluation like discussions and speculations and the second one consist of calculations using physics and formulas:

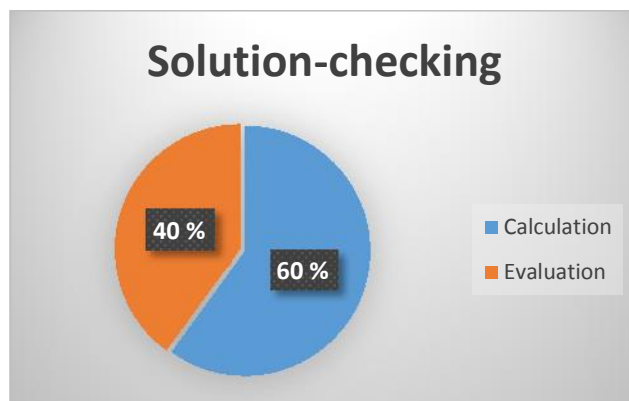


Figure 11. Distribution of *Solution-checking*, a term issued by the author

For profound understanding of the Value Flows of the case company, explaining and mapping them must go further. Iterative Actions contains two Value Flows both having two internal parts called operations. The operation is an internal part of the process (ibid., 126). As a result, we get four operations: *Components*, *Modelling*, *Calculation* and *Evaluation* which are the first four operations of an engineering

assignment. The rest of the operations are sub-categories of the fourth phase, documentation, which is not closely addressed in this study.

5.4.1 Components

How to explore and define components faster? Typically, the customer tends to copy solutions between projects as much as possible. It means, that 3D-models and the components are far ready in the beginning of a project. Even if a copied solution does not contain desired components, there is a common practice to help finding their codes and technical data: Factory standard.

It is known, that many companies working in a certain field of engineering or with a specific product has developed a factory standard to help and guide engineers in their work. The factory standard is normally found on the company's intranet.

Factory standards are indispensable when developing and constructing products. They describe necessary requirements and standards which go beyond all effective national and international standards. It is important that they feature a uniform structure and design. The rule-based format XML precisely meets these requirements. (Factory Standards 2016.)

In addition to instructions and guidelines, factory standards typically contain data of preferred and repeatedly used components to be recalled easily and quickly. Factory standards have a front page with shortcuts to their content. The author has seen usage of that kind of component databases in two large companies during his career.

It may be assumed, that factory standards are a way to expedite lookups for commonly used components, but for projects in the Research and Development, the database may not be sufficient. Moreover, due to the constantly advancing technologies and supplier-related changes, it may be advisable to explore the component data online on the web, rather than in fixed factory standard libraries. Consequently, for to avoid expiration of factory standards, they must be updated regularly, which decreases the net time saving. From the structure point of view, factory standard as a centralized tool, serves however an efficient model for calculation.

5.4.2 Modelling

Modelling is an operation where part geometries are formed of dimensioned features and assemblies constructed of parts and constraints between them. Entering metadata for models is also included in modelling time. Practically, modelling time depends on the user skills, environmental effect and performance of a 3D-software, computer and network. Efficiency of modelling should be anyway boosted to maximum. The author thinks, that the best way to advance in modelling, is the way of working inside teams.

5.4.3 Calculation

Calculation is a procedure being performed several ways, depending on the practices of the user or the company. Method to be used may depend on a product and its complexity, significance and the level of calculation, but also on applications which the designer has at hand. There are intensive calculators intended for a specific field of engineering but also all-purpose calculators to be used more superficially. Consequently, the latter are more flexible but they need more control from the user.

5.4.4 Evaluation

In this context, the term evaluation covers both thinking and interaction between the colleagues and the customer. Time needed for evaluation depends on the character of an assignment and the exact area of engineering. Evaluation can be considered as a creative part of engineering. It is well known, that ideas and innovations need time, rest and breaks to being generated. Opinions and arguments need time to form, therefore cutting short the evaluation time is not preferred in improving effectiveness of engineering.

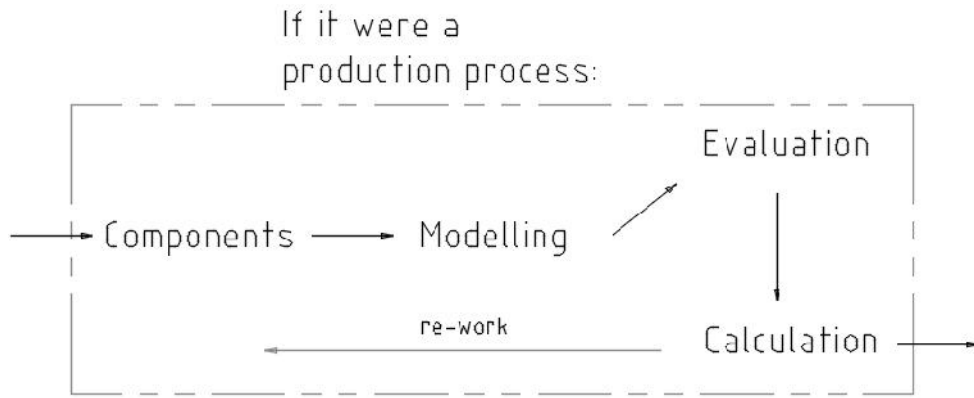


Figure 12. On the grounds of Lean (Martin 2014, 267), an imaginary production process mapped by the author.

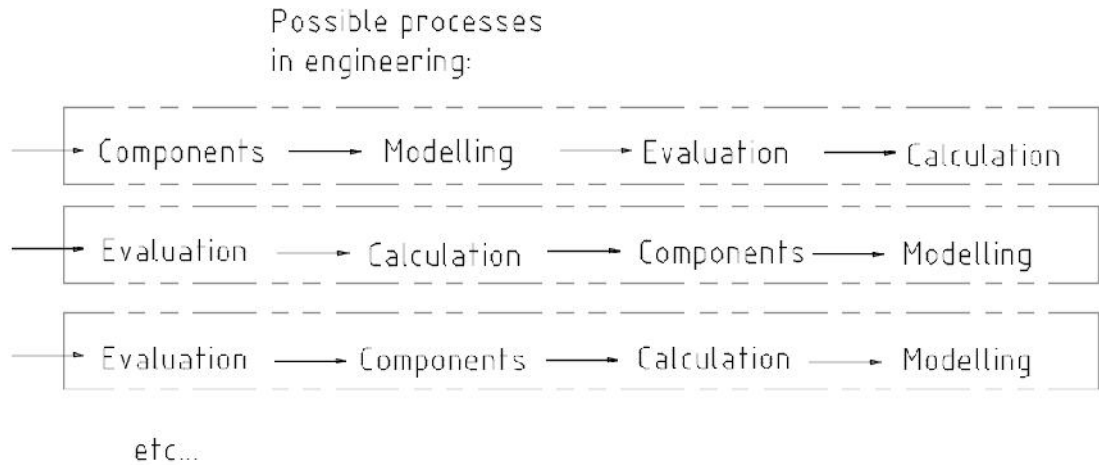


Figure 13. Examples of simple processes, mapped by the author

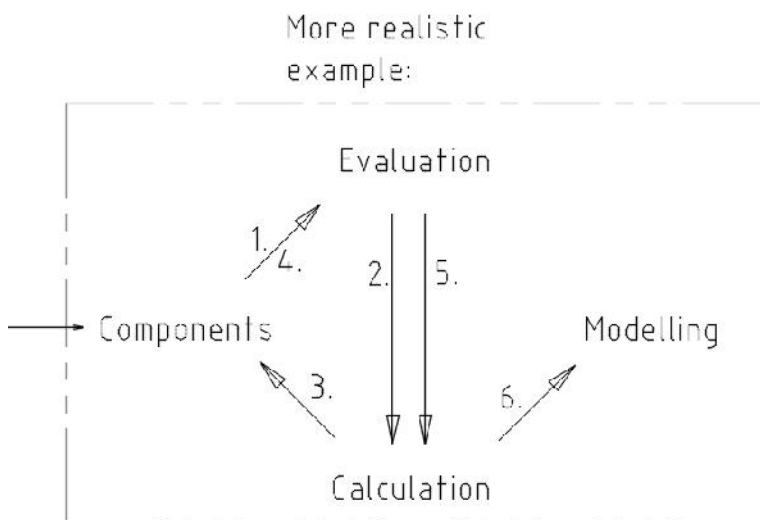


Figure 14. An illustration of an engineering process by author

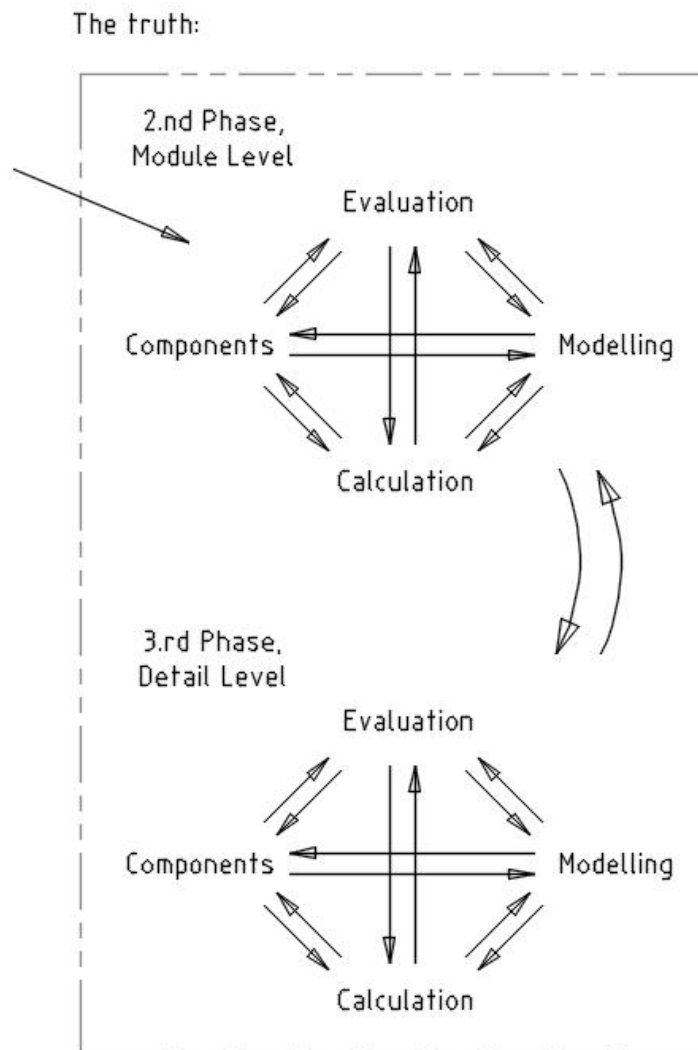


Figure 15. The closest forecast of an engineering process, the author's opinion

In the beginning, an idea was to make Value Flow Maps inside Value Stream Maps to describe Value Adding in the case company. It was noticed during the mapping, that the process sequence is impossible to define. Every time the map was thought to be ready, an earlier experience with a different process order was recalled and the direction arrows for it had to be added.

It was found impossible to describe the engineering process even with a picture. Actually, the same conclusion came, when attempted to apply Design guidelines (Jänsch & Birkhofer, 48-49) in the case company, they would had match only on a very general level and with needless items included. That conclusion came from both the author's experience and from the interviews of colleagues at the workplace. Author thinks, that to make a trustful scientific testimony for the statement,

engineering work should be scoped and metered in a great timespan in various assignments among several engineers.

5.5 Should calculation be developed?

So far, the case company's engineering assignment was allocated into the temporal phases of which Iterative Actions were recognized and split into the four operations.

It is obvious, that operations of engineering are more difficult to understand than operations of manufacturing. It would not be so, if engineering resulted same output every time. In such case, we could exactly describe the operations, plan metrics and adjust them, likewise in the case of production line where the same product is manufactured again and again by exactly the same methods.

It must also be realized, that the pie charts above apply only to a specific design task and therefore they must be considered as an example case. The Value Flows and the operations are estimated to match but the percentual amounts of each can vary a lot. Order of the operations and the shares of them depend on the character of a design assignment. For example, once the customer defines the components even in a detail level and the subcontractor just models and calculates. Or in some case, calculation is not needed because the object is not critical due to other reasons.

It may be time to admit, that an engineering assignment depends highly on what we do, for who we do, with who we work, what tools we must use etc. Actually, it would not be an engineering process if it was the same every time.

As decided during strategy planning, the case company focuses on diversification, being ready and streamlined all-round subcontractor in technology. Inevitably, different customer environments make it difficult to estimate the usefulness of Excel Tool.

However, two of the four operations are more potential for the development than the others: Components and Calculation. To improve the search of components, a factory standard should be created. It is potential way to speed up engineering. It is still restricted by the fact that a component library helps merely in work for a particular customer, since customers tend to favor company-specific components with company-related item codes and CAD-part numbers. The customer-related (i.e. product-

related) restriction concerns also calculation, but not in that extent. Even if types of the formulas depend on the product, many similar occurrences are found generally, e.g. the calculations of the steel structures, shafts, etc.

At this point, the decision to develop calculation was done. Grounds for the decision are hard to demonstrate any better, it based considerably on the personal experience. A valid existing data is impossible to find, because every company and every engineering task is different. Essential is to consider, how much to consume time in making respectable Excel calculations compared to making “disposable” calculations. The author has concluded during the Excel pilot work, that developing Excel Tool alongside the daily work does not represent such a risk that the work should not be undertaken, it just have to be conducted under certain preconditions which are listed later in the results.

However, the speculation disclosed, that there is one distinctive type of engineering which appears in every assignment: Structural engineering or rather **steel structure design**. Steel structure design is present not only in Civil engineering, but also in Mechanical engineering, where the scale is often smaller. The case company has been engineering power plants and lines, automated warehouses, cranes, service platforms, mezzanines and many kind of production line structures where statics is addressed in calculation. Statics include many reoccurring calculation tasks, regardless of whether the customer supplies warehouses or cranes. It means, that the same calculations can be applied to the several products, as far as statics is concerned.

Consequently, calculation was approved for a process for the development, but the advantages and disadvantages of the work will be continuously evaluated and cancelling will be possible. In the next chapters the overview of Excel and alternative applications will be performed.

6 Tools for calculation

In the past, the iterations were made with a pen, paper and pocket calculator. After the advance in information technology, several calculation software have been released for several areas of mechanical engineering.

6.1.1 3D CAD

If any mechanical engineer will be asked about the application what he or she mostly uses in the daily work, no doubt the answer will be some 2D or 3D Cad system.

Nowadays mechanical engineering is being conducted mostly with CAD models and drawings because they offer a graphic interface helping to understand the problem and results better than just numerical data. In other words, a CAD interface visualizes the current state of design, allowing the user to concentrate on evaluation and parameter-changing.

Most of the CAD suppliers have integrated simulation tools to the modelling environment. Yet simulation visualizes the design, it also calculates the performance of it. Simulation in 3D CAD-environment bases on a modelled geometry. With a simulation package it is possible to calculate several physical quantities, for example stress and bendings under a certain load.

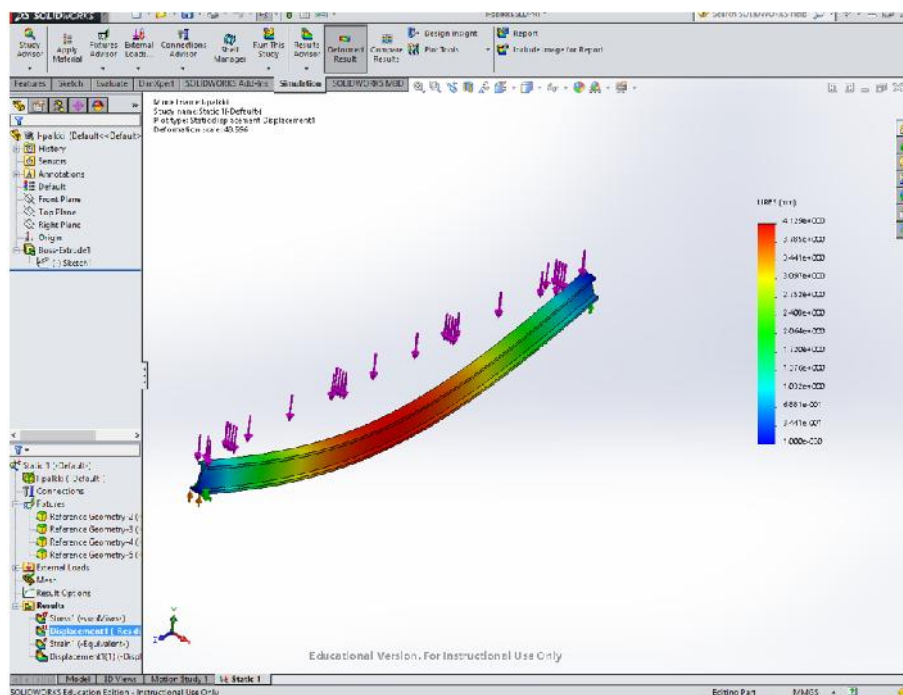


Figure 16. Solid Works simulation

Drawback of 3D CAD calculation is the unpractical sequence, as engineering starts from the modelling. Usually, you want to calculate the capability of the system first to check whether to proceed with an implementation or not. For example, you have

to decide between a linear screw and a roller chain for the transmission. You have a certain space reservation and you want to check if the cheaper roller chain mechanism would do the work. If the results after 3D modelling and simulation show the implementation too weak for the size, the modelling time was wasted. It is much faster to check an approximation for a system with an existent Excel-formula and 2D layout than to make a 3D assembly and simulation of it.

However, it might be considered to build up simulation templates for various implementations likewise the formulas would be built into Excel. For example, a simulation model for a piston mechanism can be saved and the next time, you just change the dimensions needed and run the simulation. It is just the normal way of working, the repetitive procedures in any company will be automated as much as possible, regardless what application is used.

Anyway, a full version of a 3D CAD software with its simulation add-ons will be too expensive to be purchased just for calculation. If a certain CAD software would be needed anyway, the investment for the package could be justified. The customer often provides the CAD license as part of their CAD-system. It is a desirable arrangement for a small business with a diversification strategy. From the author's point of view, a product-specialized strategy would be the only reason to end up with a 3D CAD-integrated simulation.

Purchasing even a basic 3D CAD license without the simulation is a strategic decision for a small business and therefore needs in-depth argumentation. There are several different 3D CAD software used in the markets. The investment in any of them could bind the company to a certain customer with a certain product, limiting the possibilities for offering several types of engineering services in relatively small Finnish markets.

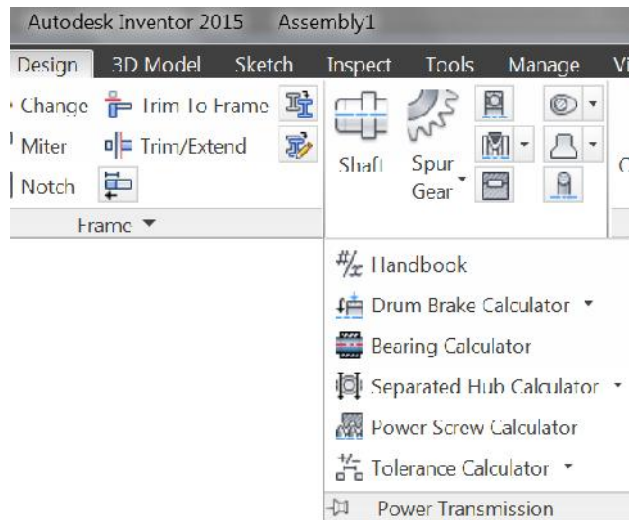


Figure 17. Calculation tools in Autodesk Inventor 2015

6.1.2 Autocad Mechanical

Autocad is a widely used 2D CAD software among mechanical engineers in several types of product environments. The case company has a license for Autocad Mechanical, which offers some useful tools also for calculation.

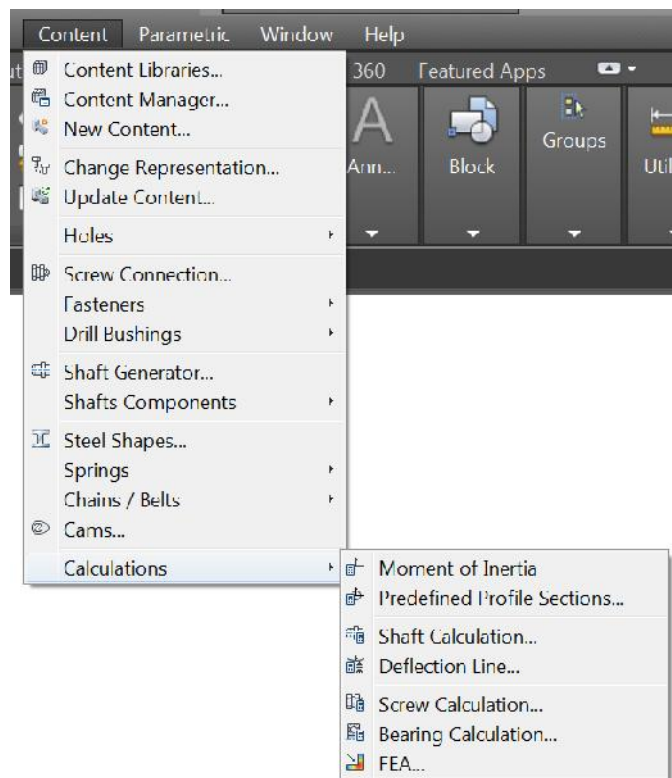


Figure 18. The calculation palette in AutoCAD Mechanical

These tools are highly professional and should definitely be utilized in a company having Autocad Mechanical. As an example of usefulness, the beam deflection calculator can solve multiple loads at irregularly set points along a beam and allows to set supports freely in limits of statics. However, it is hard or impossible to edit once set layout, it is just easier to rebuild one. In that sense, the beam deflection calculator is not good in quick comparing of different profile sections. Neither Autocad Mechanical offers all tools needed, and therefore it was not considered as a solution for calculation.

6.1.3 Mathcad

PTC is an American company which develops and provides software and services for technology manufacturers with complex products (Bloomberg Markets 2016). PTC offers a wide selection of software but also helps to integrate them to customer systems. PTC has product groups for i.a. visualization, simulation and engineering and can build up the whole platform to serve teams of engineers, collaborators and other interest groups involved in a project. PTC also develops and sells PDM-systems, which are often used side by side with a CAD-software (PTC on the Web).

PTC has also a software for the calculation needs, known as Mathcad. With Mathcad it is possible to create and manage the equations on the screen as any mathematical functions traditionally composed on the paper, adding just the possibility to edit the parameters and equations later on.

“PTC Mathcad is Engineering Math Software That Allows You to Perform, Analyze, and Share Your Most Vital Calculations.” (Description of Mathcad. n.d.)

Mathcad’s features are discussed more closely on a web site engineering.com (Jackson 2013) and the main capabilities of the software are cited in chapter *Excel versus Mathcad*.

PTC is known to the author since he has used CREO Elements, PTC’s 3D-modeling software leased by his customer. The customer utilizes also Mathcad to check results for new, more complex or high-risk designs.

During this research, the person who performs calculations at the customer was interviewed by the author. The person was asked whether he would prefer Mathcad or Ms Excel in calculation. According to him, Mathcad is far better because it shows the equations and symbols instead of hiding them in the cells as Excel does. In addition to being visible, the equations are in the correct mathematical form. The author is also familiar with the same dilemma, it is hard to edit or understand the equations in Excel, as they look more like code of a software. The interviewed raised also the question, how to introduce Excel results to the workgroup members, when the calculation procedure is hidden, showing just the input and output data. In contrast to Excel, Mathcad produces a complete document to be represented in the meetings without explaining. Further on, the person explained that Mathcad recognizes and converts different units automatically, decreasing user-errors which are often generated in Excel-equation.

Third person joined for the conversation, pointing out that the Excel spreadsheet has still advantages in the cases of tabulated calculation, where several input values can be calculated simultaneously side by side, in the rows or columns.

The interview was casual and open-ended, meant to express the thoughts and experiments of the professionals working with calculation every day. For that reason, the given answers were considered reliable material for the research. However, it was taken into account that the interviewees were personnel of a larger company and specialized in high-end calculation, whereas the research was made for a versatile small business.

The author has no personal experience of Mathcad, but during the discussion the character of the software and the differences versus Excel were understood. After the conversation, the Mathcad was considered very interesting and potential application to challenge MS Excel in calculation.

6.1.4 Microsoft Excel

Microsoft Excel provides a flexible approach to calculation. Excel is a spreadsheet which started to generalize after releasing it for Microsoft Windows in 1987. So, Excel has been used almost three decades in the business world as well as in the

public sector. Although the spreadsheets were originally developed for accounting, they started to take root more commonly in the economic life, also in mechanical engineering.

Excel-software offers to the user a possibility to build up a calculation formula for his own purposes at any time and the formula will be editable later on. Excel is rather a platform where the user can collect the data and build up formulas for his need. An effortless user interface and the usability in Windows brings it into hands for a basic user. The calculations can be saved as independent files and archived to evidence the design process in the future. Availability, suitability and flexibility for any purpose have made Excel an essential part of information technology.

The author has wondered during his career, why companies do not have any Excel Tools. If an entrepreneur considers to build up one, should it not be worthwhile also for a greater company in technology. The reason probably is, that a high-end computing software should be anyway purchased for the advanced users and basic users just ask help from them, when necessary.

As part of this research, a search for existing Excel calculators was performed on the web. Google was entered with a few queries and the results were reviewed site by site. The search produced a lot of interesting websites and links of Excel calculators in several categories. The challenge was to find the most efficient words for the queries to avoid filtering the results too much. Dozens of sites were inspected which naturally meant high expenditure of time.

Soon it was understood, that a complete, professional, illustrative, downloadable but still free Excel Tool for Mechanical Engineering would never be found, or high-likely, the searching would be waste of time.

However, many potential separate pre-made calculator-sheets also for Mechanical engineering were found and it was decided, that searching will be continued in the future in order to utilize possible findings in making own Excel Tool. The best two findings are *spreadsheetzone.com* and *excelcalcs.com*. The first one has several categories including engineering with several beam calculations and the latter offers a shareware platform for uploading and downloading spreadsheets. Excelcalc's trial-version was tested and noted to be very slim for the content. The pro-version with

pricing 99\$ a year, seemed to have plenty of content and registered users, forming like a professional community. Both sites can be recommended for a small businesses to be familiarized with.

Generally, it is either building up the Excel formulas or look for them on the web, both need time and the method being selected depends just on the user's preference. If the sheets are collected from the web, they should be still unified for the similar appearance.

6.2 Survey of Excel usage

As part of the research, a survey among engineers in the Finnish technology sector was conducted. On account of the personal experience and the interactions with colleagues, there were already a keen understanding of Excel usage with the advantages and disadvantages. Yet with the survey, it was possible to find new aspects and practises not detected previously.

As a target population in the survey was considered Finnish engineers who are experienced in mechanical engineering. Judgement sampling, a common non-probability sampling method was used in the survey. Judgement sampling is relative to Convenience sampling, which are both easy ways to form a sample. Convenience sampling bases e.g. on sample of people, who are conveniently reachable, privileged or willing to answer. (Dudovskiy, J. n.d.)

The sampling in this survey can be seen as a convenience sampling, because names and emails of the participants were known and it was the easiest way to form the sample. On the other hand, the author did not contact all the engineers he knows, but selected just them who was known to be experienced in mechanical engineering. That made it more like a judgement sampling method. (Päkkilä 2016, 11; Survey Sampling Methods. n.d.)

The judgement sampling method should be carefully used, as there is a risk that the sample does not purely represent the population, being only a suggestion of the researcher. (Dudovskiy; Survey Sampling Methods). For that reason, this survey should not have an intensive value in estimating the usefulness of Excel Tool. It was executed mainly to search for new findings on the subject.

On the other hand, in this case it helped analyzing the data, that the representatives were known for what they do or have done, as engineers experienced in mechanical engineering.

The sample of 17 representatives consisted 17 engineers, eight companies or organizations, six subcontractors, three entrepreneurs and one educator. The distribution by the gender was 16 males and one female. Hence, the pattern should have been well distributed by the different factors. All of the representatives had also experience in steel constructions.

A sampling method is essential, but also the question pattern should be designed suitably. A question can be either open or closed-ended:

When designing surveys, we often need to decide whether to use an open versus closed-ended question to get specific information. Yet we need to be aware of the fact that open and closed-ended questions each have their own strengths and weaknesses and perform in different ways. (Harris, n.d.)

Further, Harris refers to the November 2008 Post-Election Survey of Pew research, in which the open-ended questions are evidenced to produce more new and unexpected data than the close-ended (ibid.).

Because of the mentioned purpose of the case survey, the questions were designed to be open-ended. If too leading questions had been asked, possibility for new ideas or aspects would have got risked.

The survey was implemented by email as it was the only practical way to accomplish the task in reasonable time. The question pattern was short and simple on purpose. It was worried, if busy engineers would skip the email because of lack of time or considering to answer later. Yet the survey was not included any time limit for answering, in that case a participant might have delayed and forgot it.

| Sent to the representatives | | For designing and analyzing | | | |
|-----------------------------|---|-----------------------------|---|-----------------------------------|--|
| | QUESTION | EXPECTED ANSWER | EXPECTED INFORMATION | PURPOSE 1 | PURPOSE 2 |
| 1 | Have you performed mechanical engineering calculations with Excel during your career? | Yes / No | Creator / User of existing calculations | To orient to next subject | To estimate Creator / User -ratio |
| 2 | If so, have you composed Excel-equations yourself when needed? | Yes / No | Creator / User of existing calculations | To estimate Creator / User -ratio | To see significance of next answers |
| 3 | If you haven't performed calculations with Excel, what are the reasons? | Open-ended | Better application / Name of application / It's difficult...because | To find alternatives | To find obstacles preventing the usage |
| 4 | What do you think personally, is it worthwhile to develop company specific Excel Tool, or use that time for something else? | Whether Or | Whether Or | To orient to next subject | To highlight, it's person's not company's opinion. |
| 5 | If it's worthwhile to develop, why? | Open-ended | Important user-experience about the subject | To find reasons and new aspects. | |
| 6 | If it's not worthwhile to develop, why not? | Open-ended | Important user-experience about the subject | To find reasons and new aspects. | |

Figure 19. The survey questions, translated from Finnish

Because of the small sample and the sampling method, the survey was not expected to produce a definite data for analyzing the common state. As mentioned above, the purpose was to find new practices or opinions and thereby no tools for analyzing the data were used. Only the statements in the right end columns of the survey plan were used to help the evaluation of the answers (see Figure 19).

The percentage of the responses was better than expected, the 17 sent emails resulted 13 responses giving the percentage 76. Afterwards it was estimated, that the question pattern could have been greater, because the fear of the low response percentage did not actualize but the representatives were eager to answer.

The participants would probably have given longer answers with a deeper content, if they had been given examples or claims to think of, but the risk of misleading them would also have increased.

The aftermath of the survey was, that no groundbreaking ideas were born about Excel usage. One interesting issue was however addressed twice: The Excel formulas

are useful when a particular calculation is executed repeatedly. That point the author had already considered a prospect for Excel Tool. The less the formulas are created or edited the more advantage is gained. The difficult equation work in Excel should be minimized which can be achieved by automating calculation in the repetitive operations.

The answers reflected quite precisely the earlier observation during the research. A few of the most recurred opinions in the survey were: Excel is at best in simple cases and with the tabulated data, is superb for small companies and needed anyway, is inexpensive and flexible. The equations are difficult to understand and there are better applications for calculation, like Mathcad, but Mathcad is more expensive.

The preceding interview at the customer addressed the advantages of Mathcad. In the survey, four of the 13 answerers brought up Mathcad, even they were not directed to mention any alternatives. Actually, Mathcad was the only alternative for Excel being mentioned by the name. However, the pricing of Mathcad was also pointed out and according to the survey, these two rivals seemed to be quite even.

6.3 Excel versus Mathcad

Since Mathcad had come up several times during the research, it was decided to evaluate it directly against Excel. So far, the knowledge about Mathcad based on the interview of professionals at the customer but also on the answers to the survey questions. Still, for more information were searched on the web:

In math Encounters Blog, nickname Mathscinotes describes himself as a hardware development director for a telecommunications company. He has made a comparison between Excel and Mathcad. He writes that he is a daily user of both the products and according to people, considered very proficient in them. (A Problem Solved in Excel and Mathcad, 2013.)

In the end of the comparison he lists the advantages and disadvantages as follows:

Excel:

- *(Advantage) Repeating simple formulas over and over is very simple in Excel.*

- (Disadvantage) Complex formulas are a pain in Excel.
- (Disadvantage) You must handle unit conversions yourself.
- (Advantage) Power tabular data display capabilities.
- (Advantage) Everyone has access to Excel.

Mathcad:

- (Advantage) Math-like notation.
- (Advantage) Automatic unit handling.
- (Advantage/Disadvantage) Requires using a Mathcad program to repeat the analysis steps with different parameters.
- (Disadvantage) Does not display tabular data as cleanly as Excel. (ibid.)

In the end of the comparison Mathscinotes decides not to choose between the products. Both are good in their purposes. As conclusion, the comparison of the professional user in both products only established the earlier observations about the benefits and drawbacks of Mathcad and Excel.

Shortly, Mathcad is better when a problem is modelled for the first time, because of the graphic equation environment and automatic unit handling. Mathcad is designed for engineering, Excel is designed to handle the tabulated data versatily and generally, but tabulated calculation was not the prior subject to study in this research.

However, Excel is reachable for everyone, practically due to its pricing, and that was the ground of the original idea of developing Excel calculation.

Jackson (2013) writes on engineering.com about Mathcad's capabilities:

Build Engineering Equations: *Mathcad doesn't simply work like a piece of calculator software. You actually write sentences using math, algebraic and calculus symbols. You actually define your variables and write formulas out on a digital sheet of paper. Mathcad can handle complex mathematics. But overall, there's no programming equations in obtuse languages or inserting functions into spreadsheet cells. You just write equations in a natural fashion.*

Graphing Results: *Another important capability of Mathcad is that it plots out the results of your formulas and equations, including curve fitting functionality. But its not a static output. Its a dynamic representation of the equations that have been built. As variables and outputs of formulas change, so do the plots.*

Integration with CAD and CAE: *Mathcad also connects to other software tools to pull in dimensions and parameters that can be used as variables for equations. These connections enable associativity as well, so as a design changes the output of a Mathcad set of equations change as well. (ibid.)*

Jackson accounts further, that Mathcad's functionality locates between Excel spreadsheets and Mathematical modeling. Excel is everywhere but might not be the best solution for calculation. With mathematical modelling by heavy-handed, too voluminous software, he obviously refers to software like Matlab. (ibid.)

In this research, a quotation for Mathcad license was requested and the 30-days Trial version downloaded for the test use. The price for a standalone single user license appeared to be reasonable with a few hundreds annual fee. The risk is small also from diversification point of view, as Mathcad can be better applied to the different customer products than e.g. a 3D-CAD simulation software.

The price for a network license, for case of the business growth, is much higher.

The supplier announced also of the mechanical engineering package for Mathcad, which would be a worthwhile add in the case. Either the trial-version or the extra packace were not tested during this research, what was considered to do later.

6.4 Applications searched on the web

A North American company Pannam Imaging, a manufacturer of the human-machine interfaces, has expressed in their blog the top 50-list of the design engineering software. That kind of list is very useful in searching for suitable software. Yet it must be noted, such a list is only an opinion of a particular company which is operating in a certain area of technology. Anyway, the list was utilized in this research in order to find the most applicable solution to the calculation problem. All the 50 items were

swiftly estimated and the most potential of them were picked up for a closer look and are evaluated in the next chapters.

6.4.1 Matlab

Matlab is a math software which is to some extent similar with Mathcad, being however a more complex and extensive application, planned rather for the mathematicians and physicians than for a basic engineer. Matlab is more difficult to learn and demands more the mathematical skills from the user. It solves better the complicated analyzes of math and seems to be more like a tool for the science than basic engineering. Lastly, it is said to be more expensive than Mathcad (Should I Learn Mathcad or Matlab? 2014).

The opinions heard about Matlab at the customer during the interview are in-line with the message of the referenced video, so the Matlab was not considered worthy investment for the case company.

6.4.2 Engineering Power Tools Plus Edition

When hunting for a simple, cheap and sufficiently versatile calculation application for engineering, Engineering Power tools seemed to be a good catch. The application has approximately 50 individual calculators in several categories, including the mechanical. However, the content in the mechanical category was found too limited to make this application adequate for all the needs.

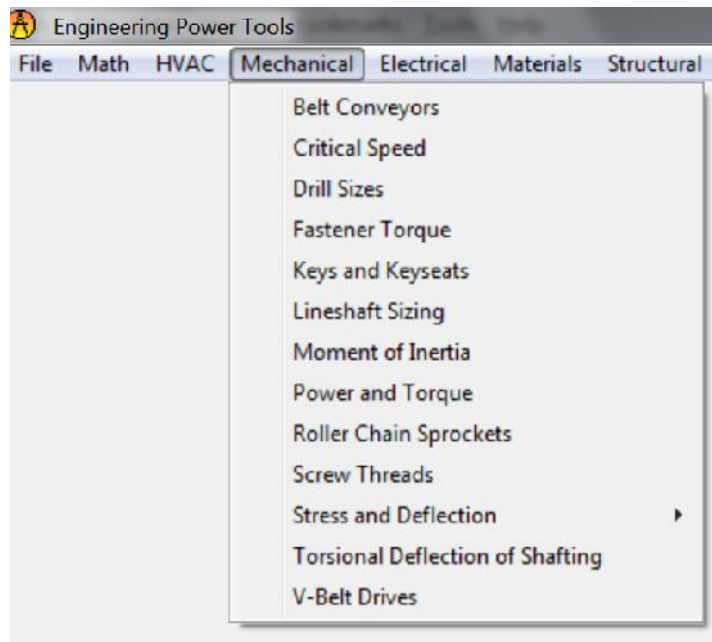


Figure 20. Engineering Power Tools, Mechanical -tool palette

The price for the calculator is very attractive. As they state on the site, the registration fee does not prevent from continuing the use after the free 30-days evaluation period. The fees for a single user are 24,95 (U.S.) with the standard edition and 49,95 (U.S.) with the Plus edition. They offer also licenses for greater workgroups and thereby the price per one user can be further decreased.

The trial-version of Plus Edition was installed and tested in this research. The operation system in the case was Windows 7. According to the website, the application is suitable for the operating systems from Windows 2000 to Windows 7, which makes the product quite old.

On the application's website - www.pwr-tools.com - can be found no information about owners or interest groups behind, but the site offers instructions and an email address for the support.

Calculators in the category Mechanical were tested. Most of them worked fine, in some of them were minor bugs found in the user interface. The best benefit of the application is reached, when it has been used together with other calculators to make double checks.

Beam bending results were compared between Engineering Power Tools and the pilot-version of Excel Tool. The results were found to be equal with a small difference, which came from the beam weight added in Excel Tool.

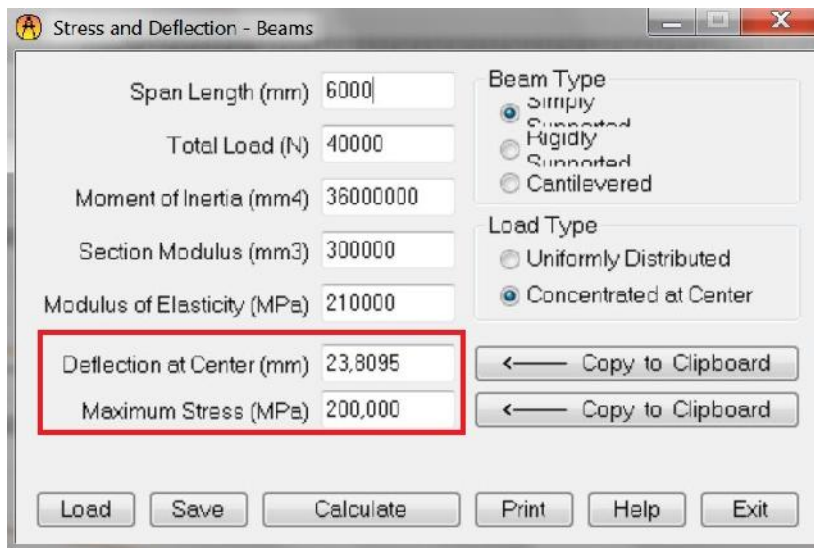


Figure 21. Beam analysis in Engineering Power Tools.

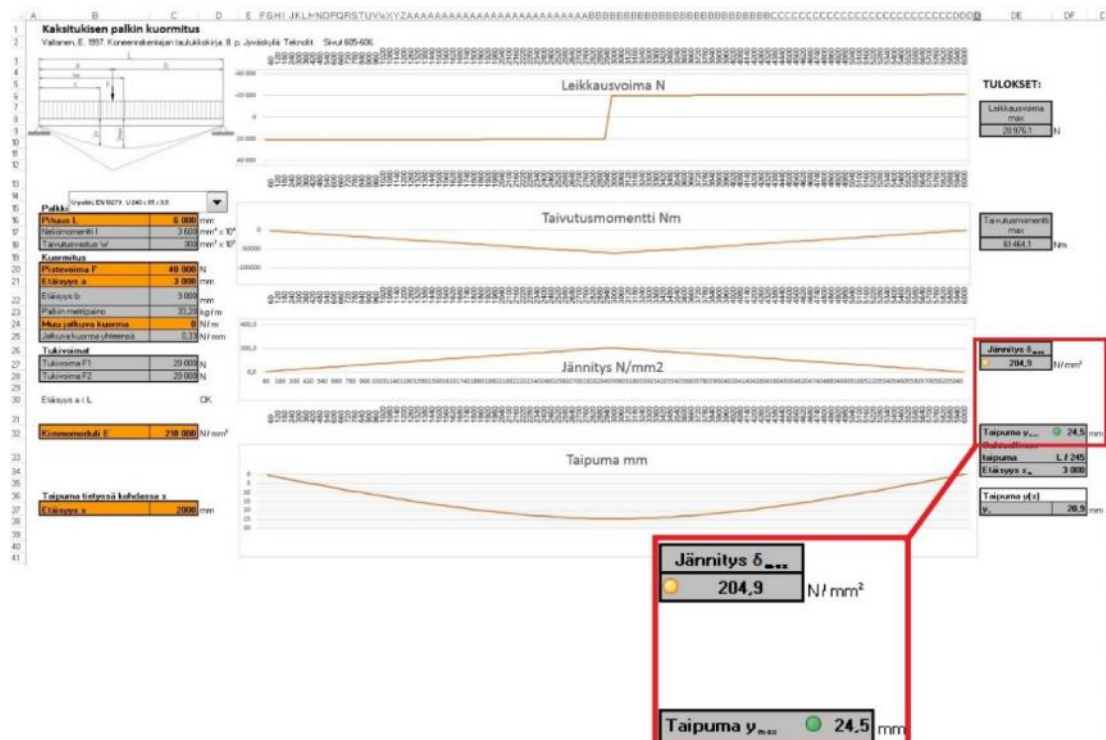


Figure 22. Beam analysis in piloted Excel Tool.

Definitely Engineering Power Tools offers the best price/quality relationship of the calculators taken for evaluation from the Pannam's list. However, it can be only the partial solution in improving the calculation process. Content of the tool is limited and there is no possibility to extend it in the future.

When searched with google, Power Tools seemed to be downloadable also from other sources. It was not clarified, if the package is available even for free and is it supported by the newer operation systems.

6.4.3 MapleSim

MapleSim is developed by Maplesoft for versatile engineering needs. According to the video on the Maplesoft's website, MapleSim highlights system-level modeling and offers better possibilities for engineers to check the requirements at the earlier stage of the design process (cf. above the design phases of VDI 2221-2222). That way the detail engineering needs less time and the total costs are decreased. As the author mentioned above in context of CAD-based simulation, he totally agrees with the significance of the design sequence. A top-down design starts from the big picture and addresses the details later. The bottom-up approach should be used only when something is designed around a standard or existing component. Minimizing of sub-level engineering was the feature that aroused the interest in the software.

According to the demo video of MapleSim, even the large assemblies can be quickly and roughly constructed for visualization and the operation charts of the CAD-components easily built up for simulation. The CAD-components from the user's library seem still to be needed.

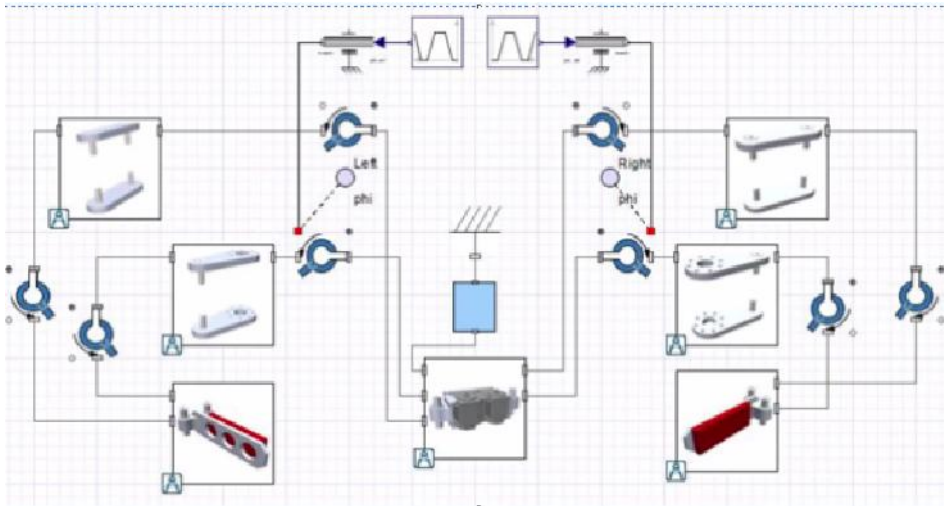


Figure 23. The approach of MapleSim

As the outcome, MapleSim was evaluated too inclusive for the basic engineering needs, having a particularly high price of 5600 EUR for the single user license. In addition, MapleSim is not used by any of the case company's customers. For the previous reasons, MapleSim was eliminated from the list.

6.4.4 Web-based calculators

There was also stated a promising, free online resource - The Engineering Toolbox - in the Pannam's list (ibid.). The Engineering Toolbox has 28 categories of which the Mechanical consist over 80 calculation examples or datasheets. Actual calculators are few found, but examples are clearly conducted with visible equations. Despite of being more informative than actual calculator resource, The Engineering Toolbox can be recommended the site to take a look at.

7 Excel Tool in practice

Making Excel Tool was started in the beginning of 2016 and has been developed both in the weekends and alongside the ordinary work. Normally such development work could not have been done on customers's time, as they pay for the hours done for their project. However, this time there was an agreement of fixed extra hours to be used for the development of Excel Tool. Now there was a great chance to build up and pilot the tool concurrently with the real design problems.

As described in the beginning, the features for the tool were far considered. The originally desired features did not change during the research, but a few new were added.

The most preferably, the tool should be just a single Excel-file, where separate calculations were in their own sheets. It was personally experienced, that looking for separate files is an extra work and non-value adding process. Allthought the files were in the same folder, in swift and numerous tasks the amount of lost time would be greater. Personally, the author prefers fewer files opened on the desktop than exploring several ones. Naturally adding numerous sheets to the file leads to lack of the space for the sheet tabs. The problem was avoided by renaming the sheets with single letters what made the tabs narrower. Additionally, Table of Contents was written in the first sheet and the headings were linked to the concerned sheets.

The second feature originally desired was the uniform appearance to be quickly adopted and easy to perceive.

Making up the tool started with gathering together the formulas created earlier. Soon, the one of the Excel's major weaknesses was realized: It was challenging to understand the equations coded in the cells, even if they were self made. It took time to go through the formulas and check whether they were correct and what stages and factors were included in. After all, the old calculations were mostly removed and new ones made.

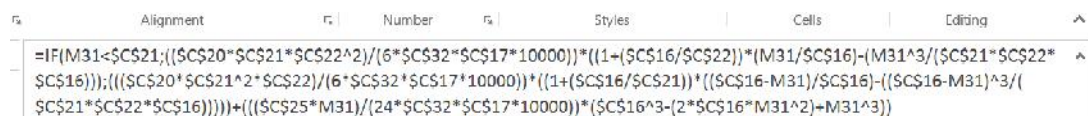


Figure 24. An Excel formula inside Beam bending calculation

The discussions at the customer resulted new aspects for the tool making. A person suggested of adding sufficiently intermediate results along the complex calculations. Thereby it would be easier to check later, what a calculation contains. The second opinion was to write explamentations on the right side of the results cells.

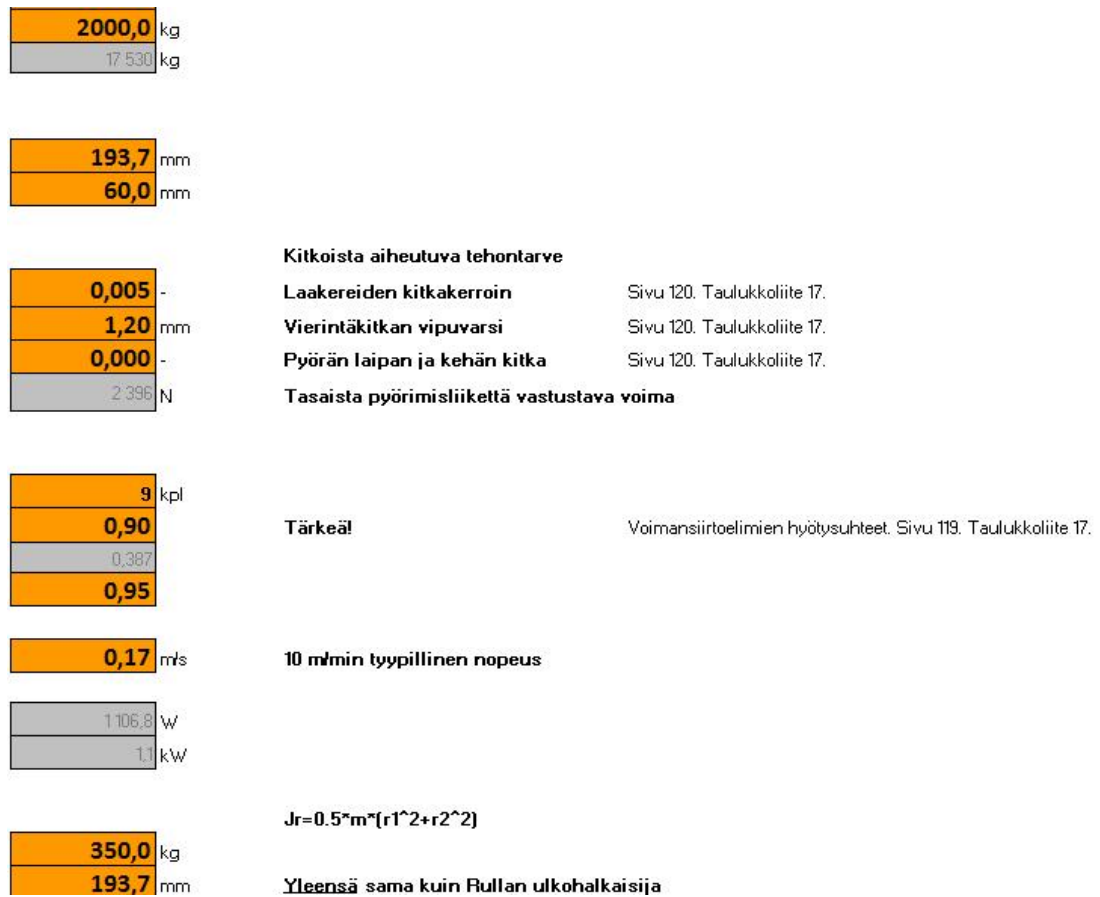


Figure 25. Capture of a multi-staged calculation. Note the explanations.

New personal aim was to concentrate on the quality and reliability of the calculations. As far as a calculation would be trusted and purpose of it explained, no need for later editing should turn out.

An objective was to keep the tool as simple as possible. That is why no macros were built in but also the use of Solver was excluded. Visual Basic for Applications VBA was also studied, but decided to leave out from the tool being too complicated for it. (Excel VBA Introduction Part 2 - Writing Your First VBA Macro. 2013.) What a powerful tools they are, but the greater will be the challenges for people to understand them.

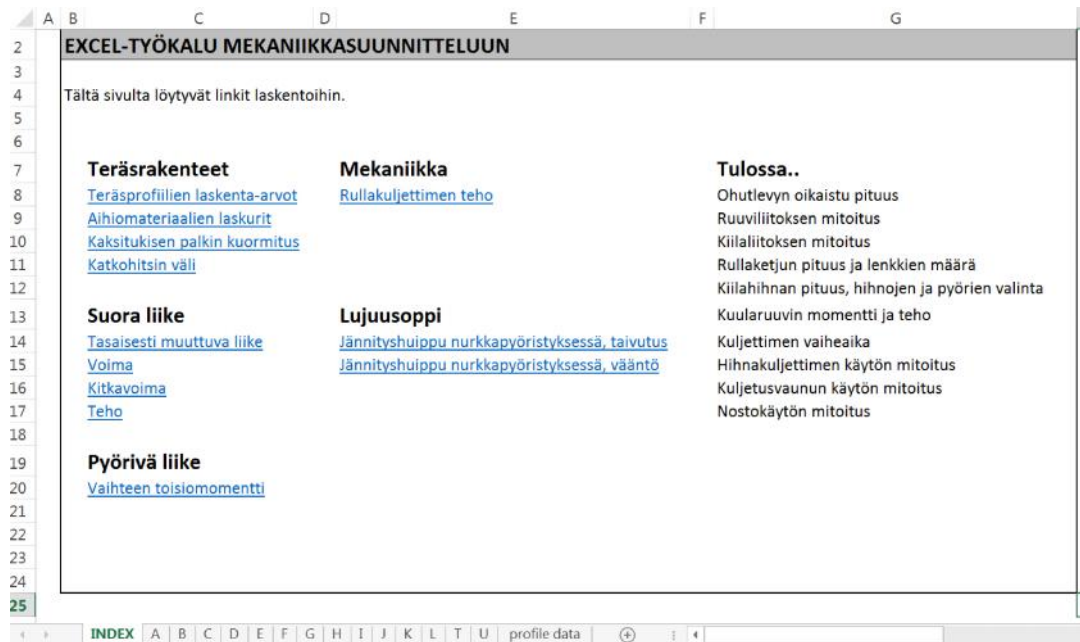


Figure 26. The front page of Excel Tool

8 Results

Excel Tool was approved to improve calculation, because any alternative calculation application providing more value for the case company was not found. Must be reminded, what the Value is (MacDivitt and Wilkinson 2012, 11-12). The calculation process was compared with the others and assessed efficient for development, just the amount of calculation did not became clear due to the versatile environment. Components process was considered the second best process for development, but it was obvious, that the benefits would have been smaller as the process was seen even more product-dependent than Calculation process.

No discoveries to obviate or minimize calculation were either done. Further, it was not considered possible to organize the processes more efficiently, because the order of the processes vary a lot depending on a design assignment and customer environment. In addition, the processes must be performed rather in several smaller steps, because the higher the number of iterative cycles the more true information will be added.

Building up a component database such as Factory standard was not evaluated worthwhile in the diversification strategy. However, during the pilot-project, a database for such general items as steel profiles and blank materials was understood worthwhile to develop, because they are used in any product at any customer.

The work to maintain Factory standard up-to-date for the components was considered as a Non-value adding process. Updating the material database is not needed as frequently, because the material standards do seldom change.

8.1 Excel Tool in calculation

8.1.1 Costs

Because the case company is small, it is not reasonable to invest either in a professional analyst or high-end calculation software. If the company shall recruit 1-2 persons in the future, they would be basic engineers performing versatile engineering assignments possibly for several customers. The employees should be able to run the calculations independently on their workstations.

The Excel would be anyway installed on their workstations, regardless the calculation solution. In that sense, the license of Excel can be considered free.

Making Excel Tool needs time which equals the money, but every new copy of the tool will be free, in comparison to the applications in the markets offering costly network licenses for a group of people.

8.1.2 Flexibility

The second great advantage of an Excel based calculator is the flexibility and extensibility of it. The possibility to control it instead of being dependent on the software suppliers helps predictability of the future. Only Mathcad offers the same dimension. Both Excel and Mathcad are rather platforms than fixed calculators.

8.1.3 Know-how

The third advantage is the learning process for everyone who creates the formulas. Understanding of mathematics, physics and Excel increases. In addition, when the

calculation is self-made, the risk for misuse decreases. The function of the calculation can be further explained to other users of a small company.

8.1.4 Challenges and limitations

Excel is not enough for the most demanding needs. It still applies to basic engineering what a subcontractor normally performs (c.f. design phases 2-3).

The competitiveness can be lost if Excel-Tool is distributed. Because an Excel-file is easy to copy and share, the competitors may soon have a ready, free and handy tool with the instructions. However, as described in the context of the strategy, the feared competition was located abroad, and Excel Tool shall be written in Finnish.

Understanding the equations later on is too difficult. The problem should be approached so, that the equations and the calculations must be composed carefully in the beginning. Difficult unit handling is also a significant drawback. It could be avoided with the same caution. Both of these disadvantages were issued in the interview, in the survey, on the web and in the pilot project of Excel Tool.

Even the similar looking design problems often slightly differ and one calculation sheet may not apply to all the cases but can be misleading. Due to the troubled editing of the equations, an existing calculation is difficult to multiply and edit for a new one. It is often easier to create a new calculation from the beginning.

It was understood during the research that the benefit of using Excel for creating the multi-staged equations in Mechanical engineering - depend on how product oriented a business is.

A significant discovery was made when splitting the engineering processes into the parts: Usefulness of the Excel calculator has complicated connection to the strategy.

For the case company, which has chosen the diversification strategy, utilizing Excel Tool in calculation would be more challenging. The broad range of customers and products would result a constantly growing need for different types of calculators to be created. Also recalling the previous calculators would be more demanding, therefore a simple structure of the tool and clear instructions should be ensured.

A significant insight was, how common static calculation is - in the engineering range of the company. Strength, bending, torsion and combined stresses are present at everywhere.

Although the Excel's data collection features were not primarily addressed in the study, *Steel profile selection tool* outputting the section data was found very versatile. For the previous reasons, static calculation and the profile selection tool will be the primary objects for development in the future.



Figure 27. The steel profile selection tool uses a database in another sheet.

9 Conclusions

It can be concluded, that Excel Tool is the best or second best practice when versatile engineering in flexible and low-risk small business is concerned. Mathcad was not tested in practice which must be done in the near future. If Mathcad shows remarkable advantages, the payback time of higher pricing must be evaluated.

Despite the diversification strategy, Excel calculation can speed up engineering and improve the competitiveness of a small business. So that using time for developing Excel Tool would not be a new Non-value adding process, it must be done properly

and only in certain cases. The most essential prerequisite is to understand the margins in which Excel Tool will be developed. There are preconditions, which must be fulfilled in order to obtain profitable benefit. The preconditions are:

1. The Excel Tool is applied in the subcontractor's responsibility area (design phases 2-3). The first phase is conducted by the customer and using software such as Mathcad or 3D CAD simulation.
2. Excel Tool is developed only for general calculations.
3. Equations are made carefully so they can be trusted.
4. Calculations must have explanations of applicability.
5. Calculations must have sufficient amount of intermediate results.
6. Excel Tool must be a single file with a front page and links to sheets.
7. Calculations in the sheets must have uniform appearance.
8. A certification mark is added for a new calculation after the results are proved.
9. Excel Tool is not applied to presentations or demonstrations.
10. Making Excel Tool does not disturb the actual project work.

Additional benefit is obtained:

1. When Excel Tool is used for double-checks with other calculation software.
2. Through better learning and understanding the technical dependencies of design problems.

Excel Tool is applicable for the case company because:

1. The company is small (1-3 persons)
2. Of high economic risk of investing in more expensive software.
3. Excel is used in any case. The profit comes from using it more efficiently.

10 Initial action plan

The advantages of Excel Tool were evaluated greater than the disadvantages of using time to develop it. Therefore, **the development can be continued with the preconditions** stated above.

Existing Excel-calculation spreadsheets on the web will be utilized, in order to copy and modify them.

For the time being, other calculation applications will be used concurrently with Excel Tool to compare and verify results.

In addition, **Mathcad will be tested** with the Mechanical engineering package in practice.

During the research, an idea of selling Excel Tool later arose. The idea was rejected because there are already so many unfinished applications available.

Lastly, it was considered if Excel formulas could be edited using a separate application. This would remove the disadvantage of complex Excel formulas. Possible implementations will be examined.

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