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Product Design Process improvement based on Agile Project Management principles

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Author's Declaration

I have written the Master's thesis independently.

All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.

Master's thesis is completed under the lecturer's Roman Zahharov's supervision

"....." December 2015

Author signature

Master's thesis is in accordance with terms and requirements "....." December 2015

Supervisor.....signature.

Accepted for defense

..... chairman of defense commission

"....." May 2015

..... signature

Abstract

This thesis studies the improvement of a product design process in a company dealing with project-based production automation, systems design and manufacturing. Improvement of the design process is the area chosen as the focus of the study – as having the most leverage over the final quality of the delivered products. The study is carried out from the point of view of Tech Group – where the author holds the position of a customer and project manager.

The author studies the history and status quo of the goals and capabilities of the enterprise to justify the plan of action. Procedures are developed and introduced to facilitate a design process that is inherently flexible and focused on using the time allotted for delivering as much value to the customer as possible. The approach acknowledges and mitigates project related risks through active cooperation of project stakeholders and the transparency of tools supporting the product design process. The improved product design process should help the company increase the quality of its products. This will benefit the company both in the short-term – through lower overall project execution costs – and the long-term – through better reputation with its customers.

The tools and methods for the refinement of the product design process are based on the principles of Agile Project Management (APM) – a set of methodologies developed within the software development industry. The philosophy of APM and the needs of project based design at Tech Group share many similarities.

The thesis concludes with a practical example of a customer project executed at Tech Group. The particular example highlights how an iterative approach, cooperation and an acknowledgement of a floating scope in regards to the task of the project has helped the design team to deal with many difficulties during the project life-cycle. The result of implementing APM methods in the design process is a project delivered without delays, 20% under budget, utilizing 80% of the budgeted design hours. The improved product design process retains the agility and flexibility (short delivery times and large range of shippable products) in regards to all projects the company undertakes. The improved process significantly lowers the chances of producing products which require extensive troubleshooting after the customer project commissioning phase.

Keywords: Product Design, Agile Project Management, Engineer to Order, Manufacturing, *New* Product Development, Organizational Learning, Production Automation

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Introduction

There are several types of projects that a production company may have to deal with in the real world. On the one hand, when the goal of the project is clear and the means of attaining it can be planned in advance – the waterfall project management methodology – which is extensively outlined in the Project Management Book of Knowledge (PMBOK) – should be the go to method for handling the task at hand. There are, however, situations and production frameworks, where little is known about the specifics of the result as well as the means of achieving it. Engineer to Order (ETO) manufacturing of production line automation is one such task. The level of uncertainty naturally depends on the current level of company experience and the newness of the task at hand – when it's the 3rd or nth automation line of that kind, which had once already been built or set up by the company – the tasks are relatively clear and the modifications that are needed to adapt it to a new customer or site can be outlined with a good degree of certainty beforehand. The execution of such tasks may be well planned for in a linear modeling fashion utilizing waterfall Gant charts. Or as Ogunnaike and Ray wrote in 1994: It is typical to adopt the defined (theoretical) modeling approach when the underlying mechanisms by which a process operates are reasonably understood. When the process is too complicated for the defined approach, the empirical approach is the appropriate choice. [15]

When your project or product is a first of its kind for the company – waterfall methods may be utilized, but, as practice has shown, when applied to design, they can end up as a picture far removed from reality and the actual way problems are handled during the project execution stages – they are thus a poor model for what actually goes on at the company. Furthermore, a structure that operates using linear thinking as a basis for its activity may be led astray by the will to adhere to a model which has little relevance to how some problems are actually solved. Deadlines and Milestones turn into points where some problems may be swept under the rug and the philosophy of “good-enough” can take over. This all has detrimental effects both on the quality of the product and the direct costs the company may incur while fixing “bugs” that come up during the commissioning and operation of its products. The thesis will deal with the kinds of projects where the fact that – you know the least about your project on its very first day – is especially obvious.

The author wishes to advocate the introduction of project management methods that are advertised as being more fitting for dealing with high uncertainty of the goals and means into the routine of an ETO production automation company. The main basis for this will be the borrowing from the methodologies residing under the umbrella term of Agile Project Management or APM, where the uncertainty of project requirements and the algorithms for their execution is high at the onset of the project. The thesis will thus focus on the following question:

How to improve the ETO product design process at Tech Group?

The objectives that will be tackled to ascertain the answer are:

- 1) *Ascertain what empirical tools exist that can improve the project-based product design process.*
- 2) *Ascertain why a good product design process is needed by Tech Group.*
- 3) *Provide practical tools and methods supporting the improved 4design process.*

Overview of the approach

The specifics of the manufacturing paradigm in production automation are such that all projects are naturally split into two large parallel processes, one of which is aimed at transforming and manipulating information and the other – matter and energy:

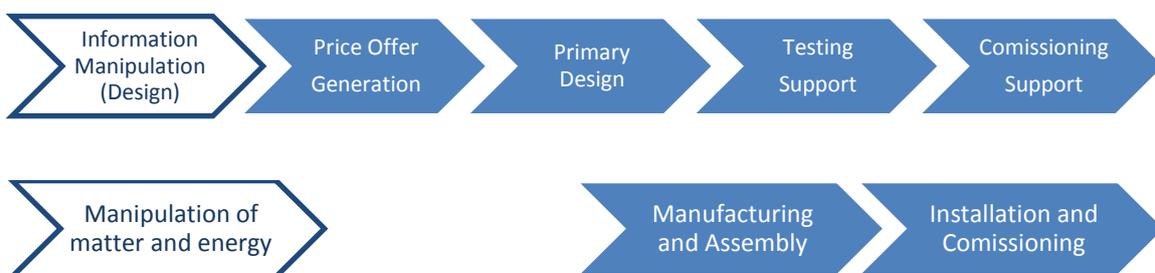


Figure 1 – Simplified model of an ETO design and production process

If we make a simple linear model we will see that the design process supports the ETO project through all of its execution stages. The primary focus of this thesis will be on the primary product design stage where most of the design work is executed. As it will be demonstrated his stage has the most leverage over the outcome of the project. The process of manufacturing and ordering of the parts and components will not be of much interest to our study. Furthermore Tech Group outsources the bulk of its production process to outside companies – so production will be simply viewed as a delay contingent on the production

capacities of the company and its subcontractors. Furthermore, design is by right considered the area which has the most leverage on the ease or difficulty of execution of manufacturing projects. As such design will be viewed as the key process of a one-off ETO manufacturing project – the improvement of which this thesis will concentrate on.

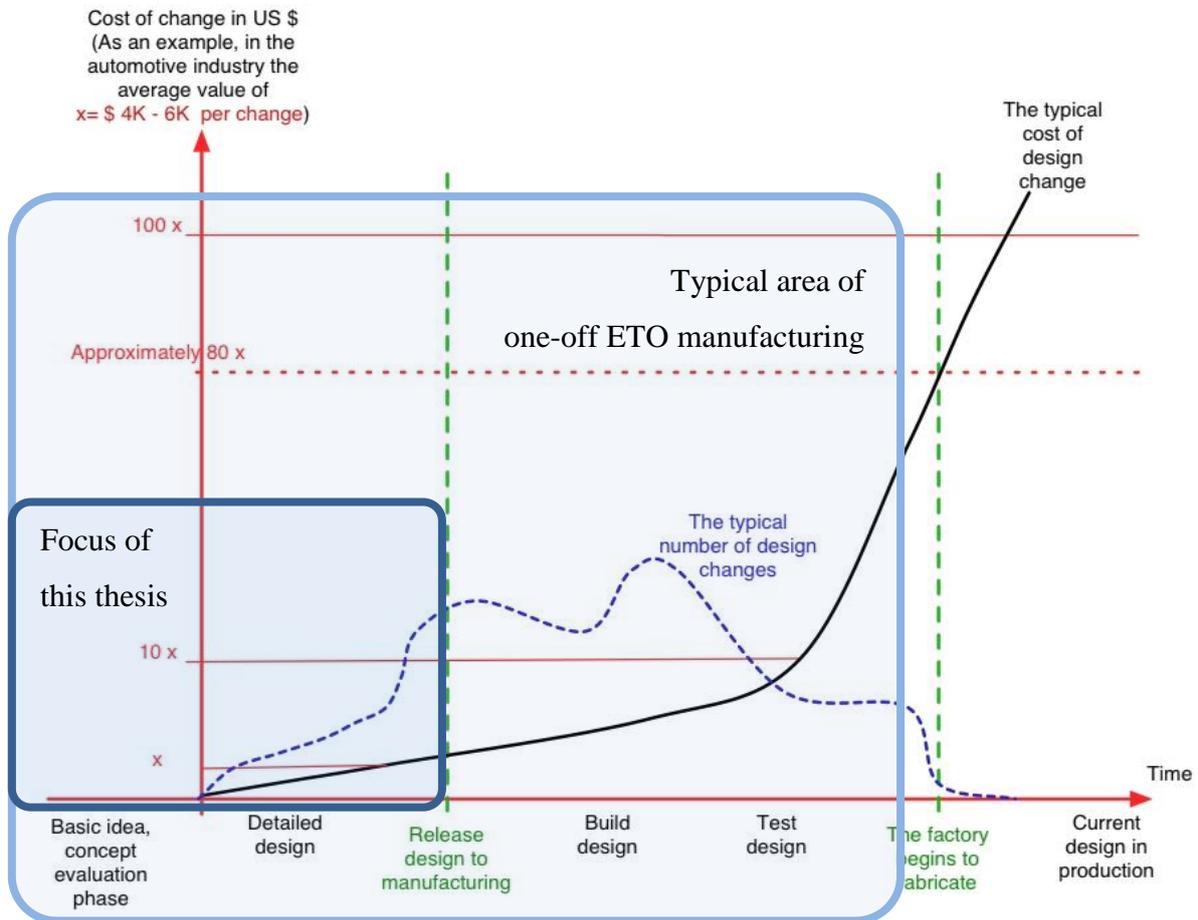


Figure 2 – Typical cost of changes to the product's design during its life-cycle phases (Ranky, 2005) [19]

During the writing of this thesis the author implemented several tools and methods for refining the product design process. The tools and methods discussed in this thesis are the ones that were welcomed by the stakeholders of the design. Within the thesis the author does his best to approach matters systemically – acknowledging the presence of hidden long term costs and benefits which may be achieved when seemingly small changes are made to critical parts of a complex manufacturing system. The goal of the author is not to transform the existing design process but to take the most suitable and practical ideas from the existing approach and augment them with tools and ideas from APM, producing a process that would fit the company's actual needs and respect existing constraints.

Necessity and Novelty

After several months at working for Tech Group, a company handling both production subcontracting and the execution of ETO production automation projects the author has witnessed an immense disparity of management needs in regards to serial production and ETO projects. The company handles both kinds of projects on a daily basis – being competent in both areas of business is clearly necessary to the company, while increasing the competence in ETO production is the company`s strategic goal.

Many approaches that are vital to handling of ETO projects implemented in the company are already reminiscent of methods which are advocated by various branches of APM. The author supposes that the best way to handle the design of ETO production automation projects is to explicitly embrace their inherent uncertainty and treat them in a drastically different manner to manufacturing practices. Fitting elements of an approach designed by the software industry to manufacturing is a task that needs care and time to execute. Furthermore:

1. There is exceedingly little literature or case studies done on the matter of adapting APM approaches to other industries.
2. APM approaches are not covered in the curriculum of many university programmes that deal with manufacturing in a notable way.

It is for these reasons that the author finds the problem both of interest and necessity and wishes to undertake a more in depth study of the matter in the form of this thesis.

Thesis Structure

The thesis will start out by giving a theoretical overview of a manufacturing company, project management, organizational learning and agile project management and other concepts used to build the practical tools described in this thesis.

Next we will look at the goals of Tech Group – what they are contingent upon, and how organizational learning and the introduction of agile project management principles to ETO projects is paramount to improving the wellbeing of the company as a whole.

The thesis will conclude with an overview of the refined design process and practical tools that assist its implementation with the goal of improving the quality of the company`s ETO production automation projects for its customers.

1. Theoretical background

1.1. A model of a manufacturing system

There are many ways in which to approach the abstract description of any system in order to try and better understand it. One of the ways which the author found to be concise and attractive comes from the Engineer's Handbook website (2015). It is, of course, but a single of the myriad of ways to represent a manufacturing system and may, perhaps, be retrofitted to the author's own biased beliefs based on the ideas he wants to get across in this thesis.

To cite from this public source: Manufacturing is generally a complex activity, involving people possessing a broad range of disciplines and skills and a wide variety of machinery, equipment, and tooling with various levels of automation, including computers, robots, and material-handling equipment. Manufacturing activities must be responsive to several demands and trends:

- A product must fully meet design requirements and specifications.
- A product must be manufactured by the most economical methods in order to minimize costs.
- Quality must be built into the product at each stage, from design to assembly, rather than relying on quality testing after the product is made.
- In a highly competitive environment, production methods must be sufficiently flexible so as to respond to changing market demands, types of products, production rates, production quantities, and on-time delivery to the customer.
- Manufacturing activities must be viewed as a large system, each part of which is interrelated to others. Such systems can be modelled in order to study the effect of factors such as changes in market demands, product design, material and various other costs, and production methods on product quality and cost.
- New developments in materials, production methods, and computer integration of both technological and managerial activities in a manufacturing organization must constantly be evaluated with a view to their timely and economic implementation.
- The manufacturing organization must constantly strive for higher productivity, defined as the optimum use of all its resources: materials, machines, energy, capital, labour and technology. Output per employee per hour in all phases must be maximized.[7]

Whichever model of a system one chooses, however, one must not forget that this is only a model – and the real system is far more complex than a single person can properly imagine (this is a priori true for any systems consisting of more than one person). From this particular model we can extract the essential areas which manufacturing organizations must focus on in order to function well:

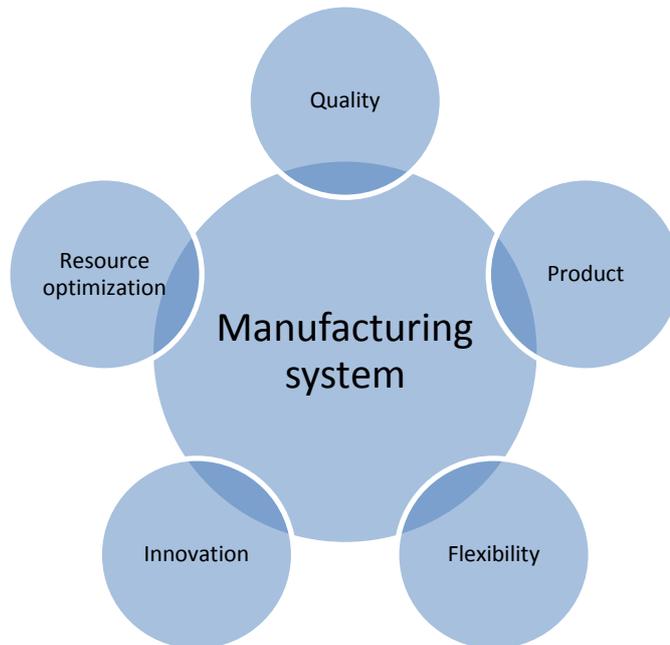


Figure 3 – A model of the functional pillars of a manufacturing system – top view

The thesis will try to approach these areas, as the fifth element in the above list above would indicate – systemically – acknowledging their interconnectedness and their ability to influence one another and produce effects which are not closely related in either time nor space. The sum of these components is a manufacturing system, the overall efficiency of which depends not only on the quality of the components as stand-alone entities but in a way in which they cooperate and are in tune with each other, for example:

1. An excellent quality policy and motivated staff are useless if the assembled high-quality product does not fulfill the purpose desired by the client.
2. Aggressive resource optimization and overspecialization can turn deadly if the environmental requirements on the company take an unexpected turn.
3. An excellent product from the standpoint of technical characteristics normally used as objective metrics for this kind of product may mean nothing, when what the client wants and needs is something completely different.

These areas thus need to be approached holistically – each of them having qualia that need to be tuned to the surrounding world as well as the other internal elements of the manufacturing system to get the best “sound” out of a company. Just as with production lines – the principle of eliminating the bottleneck or augmenting the weakest link should take precedence over anything else, to get the most out of the effort exerted to improve the current structure. Unlike a production line there are, however, few to none universal metrics between these domains which would easily indicate where this effort is to be focused and what margin of improvement is needed in that direction. One universal force that is usually restraining the attainment of unrestrained excellence in any of the areas can be viewed as resource availability – which can be described, for simplicity, in either time or money that is needed to improve upon the current situation.

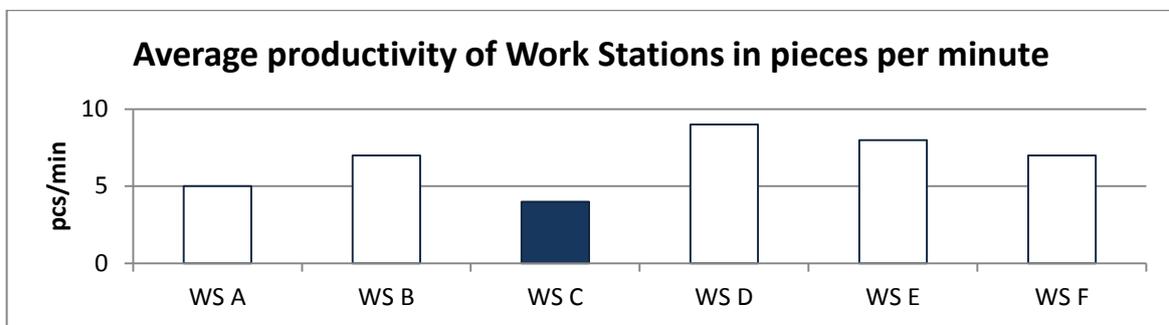


Figure 4 – Bottleneck analysis of a hypothetical production line

The graph outlined in Figure 3 can be attained in serial production through the scientific method popularized by Taylor at the turn of the 19th century – time studies. The method is straightforward and produces results with a single metric – time. The assessment of the results may be done using an algorithm; one such assessment routine may look as follows:

- 1) Assess the monetary costs and productivity advantages of alternatives for improving station C.
- 2) Assess scenarios of using these alternatives in practice, i.e. the increased turnover, reduced workforce costs etc (these comparisons can all be done using a single metric of, for example, money).
- 3) Assess the payback period taking points 1 and 2 into account.
- 4) Take a guess of whether the risk of locking up capital for the investment into improving C will be fair in regards to the market need for the products that can utilize C in their production routings.

As such, to assess the improvement of most manufacturing operations we can use two basic metrics – time and money. The fourth assessment of whether to take the leap to implementing improvements is still a creative decision that needs to be done while taking into account the broader picture of the markets, the capabilities of the company and alternative options of using the improvements to C in innovative ways.

Things however get far more complex as we step back and gaze upon the manufacturing system with such broad definitions as „product“, „quality“, „innovation“, „resource optimization“ and „flexibility“. What metrics do we use? Who is the arbiter assigning the score for the assessment? What weights to use when compounding these metrics and wishing to compare them amongst each other? Predicting a future of a complex system is a task of immense proportions, especially if one wants to assess its varying alternative future states. This task is both too time-consuming and thus too expensive to do well through analysis – breaking the complex system down to its constituent components and trying to improve them on their own so that the result would benefit the whole in a significant “proven” manner. Suppose we did have the instruments and resources to precisely measure along three common dimensions the areas supporting the company’s business – it is likely that the picture we would end up with would be as useful to our further analysis as the one presented below:

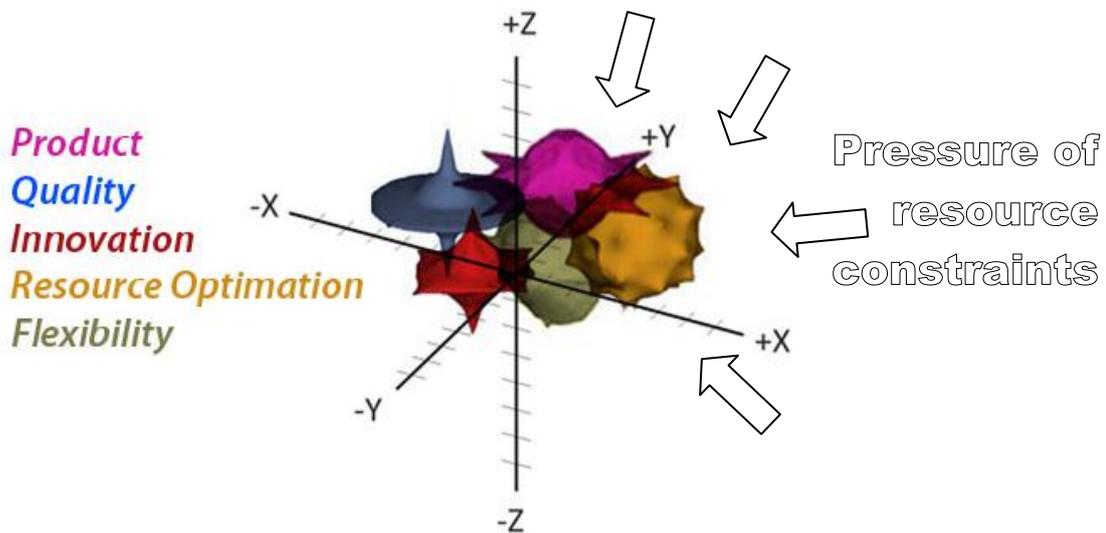


Figure 5 – The property mollusk of a manufacturing system

One thing we will know for certain is that there is constant pressure exerted on all areas of business – hindering their outward expansion – through the resource constraints that any finite system will impose. Due to the difficulties of holistically quantifying a production

system – a qualitative approach will thus be used in the thesis with a stress on respecting the observed existing environmental constraints.

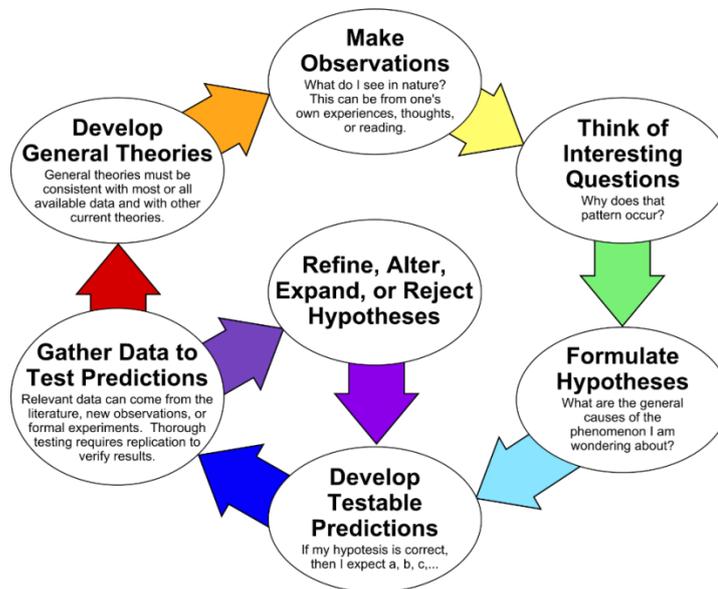


Figure 6 – The Scientific method as an ongoing process (Garland, 2015) [8]

The following propositions will be used in this thesis:

- **Observation:** execution of ETO projects is important to the well-being of Tech Group and the turnover it generates per employee.
- **Question:** can we eliminate the inconsistencies in the execution of ETO projects?
- **Hypothesis:** we can improve the outcome of ETO projects by focusing first and foremost on the portion of the project process having the most leverage over their outcome – design; design can be improved by refining the design process in light of agile project management methodologies and organizational learning.
- **Prediction:** ETO projects will be executed with less overall cost and with fewer hours of rework – benefitting the company in the short-term and the long-term through better reputation, repeat business and word of mouth advertising.
- **Testing and Refinement:** the hypotheses discussed herein were being developed as it was being implemented and tested with feedback from project stakeholders being received incrementally – the Thesis will focus on the tools and methods that seemed most beneficial to the stakeholders. This refinement period is only 6 months old as of the date of this Thesis – and will continue into the future.

1.2. Systems Thinking

If a company is a complex mechanism which is prohibitively costly to describe with due diligence – how then do we plan for and execute the changes which would be beneficial to it? One certain part of the answer is “with care”. This in turn means that changes should be implemented iteratively with the results of these changes being monitored for unintended consequence – doing one’s best to avoid the situation where “today’s problems come from yesterday’s solutions” (Senge, 1994)[21]. The author will try to use approaches that deal with clearing obstacles in the existing business processes of the company rather than superimposing idealized sets of regulations that claim to make specific processes shine on their own. The company will be viewed as an organism that has withstood the test of time and the processes that have evolved to keep it in balance between the interests of its internal and external stakeholders will be treated with due respect. The approaches that the author will try to adhere to can be combined under the umbrella term of “systems thinking”. As written by Richard Daft in his book “The Leadership Experience”:

Systems thinking means the ability to see the synergy of the whole rather than just the separate elements of a system and to learn to reinforce or change whole system patterns. Many people have been trained to solve problems by breaking a complex system, such as an organization, into discrete parts and working to make each part perform as well as possible. However, the success of each piece does not add up to the success of the whole. In fact, sometimes changing one part to make it better actually makes the whole system function less effectively. (Daft, 2008) [6]

The areas where improvement is needed will be decided, albeit inevitably subjectively, based on the experience of the author with the company and the views and comments of the company’s internal stakeholders – the employees and management. A notable point is that systems thinking focuses on finding internal underlying causes for problems instead of appealing to outside factors hindering the attainment of excellence. The external factors are surely there, but they are taken as a given – i.e. something that cannot be avoided – and what is actually studied is that which the organization can control: the internal – or how to become better within the given set of current environmental constraints.

Through a complex corroboration of probabilistic circumstances the Author has come across the qualification of systemic complexity that fits the bounds of this thesis exceedingly well. This qualification example was compiled in 1959, yet it is difficult to disagree with it to this day – even though our understanding in every category has expanded in breadth and grown in depth considerably – the relative complexity of the examples used in these categories remains unchanged.

Table 1 – Stafford Beer's classification of systems (emphasis by author) (Beer, 1967) [2]

Systems	Simple	Complex	Exceedingly Complex
Deterministic	Window Catch	Electronic Digital	-
	Billiards	Planetary system	-
	Machine-shop lay-out	<u>Automation</u>	.
Probabilistic	Penny Tossing	Stockholding	The Economy
	Jellyfish movement	Conditioned reflexes	The Brain
	Statistical quality control	Industrial profitability	<u>The Company</u>

There is little to add to the table above but to highlight the complexity of the systems that the current thesis will deal with:

- Improving the functioning of an exceedingly complex probabilistic entity – the company
- Dealing in the area of deterministically complex tasks such as automation.

The problem of improving Tech Group will be looked upon as a soft systemic problem with a general goal of improving the company being arrived at through the improvement of the framework used in the design of ETO projects. The result of the research will be the refined design process with a set of tools aimed at stressing learning and continued improvement within the enterprise. Some goalposts for this endeavor will be taken from APM methodologies. It is supposed that the implementation of these methodologies will help promote organizational learning, inter- and intradepartmental cooperation that will benefit the company on many levels.

1.3. Project management

Due to the nature of the project of writing a thesis – the author is obliged to acquaint the reader with or refresh in his or her mind the basic concept of project management. To manage means to be in charge of. And to be in charge of an abstract entity such as a project means to do what is necessary to achieve the goals of that project. What is a project?

According to the Project Management Institute: “a project is temporary in that it has a defined beginning and end in time, and therefore defined scope and resources; and a project is unique in that it is not a routine operation, but a specific set of operations designed to accomplish a singular goal” (PMI.org) [18].

A project in its broadest sense is thus a human endeavor to manipulate the physical world into a desired state within a specific set of limiting factors. But to prevent this concept from being completely interchangeable with the concept of “activity” – uniqueness, multiplicity of underlying processes and unity of the whole endeavor are a prerequisite for an arbitrary set of activities to be called a project. A project thus:

- Has a specific objective
- Has defined start and end dates
- Consumes human and non-human resources
- Is multifunctional (PMI, 2013)[17]

Project management (PM) in its turn is a set of activities that is directed at keeping the underlying processes on track with the goal and within the constraints of the overall project or, again in the words of the Project Management Institute: “the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements” (PMI, 2008) [16].

Two key concepts being the need for controlling resources and the existence of specific success criteria – how much and what kind of planning organizing or motivating is involved is a derivative of these key constraints. There have been many notable attempts to standardize project management – the first dedicated attempt by the International Organization for Standardization (ISO) having been made quite recently in 2012 (ISO 21500: 2012 - Guidance on project management). Empirically, however, a set of guidelines de facto accepted as a standard is by popular consensus is considered to be the “Guide to the Project Management Body of Knowledge”. It is a set of books which present

a set of standard terminology and guidelines for project management. The Fifth Edition (2013) is the document resulting from work overseen by the Project Management Institute (PMI). Earlier versions were recognized as standards by the American National Standards Institute (ANSI) which assigns standards in the United States (ANSI/PMI 99-001-2008) and the Institute of Electrical and Electronics Engineers (IEEE 1490-2011). (IEEE, 2011) [11]

The standards outlined by these documents will be taken as basis for assessing the current state of the project management processes employed at Tech Group in the second part of this thesis. In short, the main distinctive activities of the traditional approach to project management fall into five generic groups as illustrated by the following diagram:

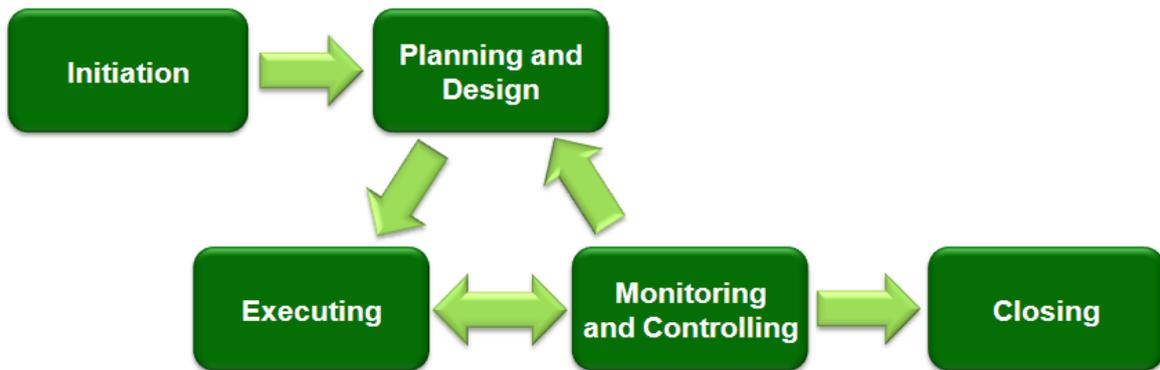


Figure 7 – Typical development phases of an engineering project (PMI, 2013)[17]

As with any soft problem however, this is by no means the single and definitive way to look at a given project. For most purposes any project can be retrofitted to this standard model, but, to borrow from Kierkegaard – while life must be experienced backwards – it must be lived forwards – what this means is that one needs a practical and less general model which can be used a solid basis for structuring a certain set of projects upon. A useful project management model for a certain type of process must be robust seamless and, where possible, well-defined. ETO projects are an area where the last criteria of how well-defined your project process is in fact a trade-off of apparent certainty for flexibility and preparedness for the unforeseen. Therefore one must empirically find a point between a rigidly defined and an uncontrolled ETO design process. An approach the author wishes to introduce is to create a set of tools to handle the actual observed cases events the ETO design process stakeholders are faced with. This less specific approach and framework would be quick and easy to reduce and refine to the needs of every unique project at its onset. Furthermore the primary goal of the author is the encouragement of effective

cooperation of existing resources within the company as is outlined by Kerzner in his 1979 book „Project Management: A Systems Approach to Planning, Scheduling, and Controlling“:

Quite often people misunderstand the concept [of PM] because they have ongoing projects within their company and feel they are using project management to control these activities. In such a case, the following might be considered an appropriate definition:

Project management is the art of creating the illusion that any outcome is the result of predetermined deliberate acts when, in fact, it was dumb luck.

Although this might be the way that some companies are running their projects, this is not project management. Project management is designed to make better use of existing resources by getting work to flow horizontally [functional resources and units] as well as vertically [management hierarchy] within the company. This approach does not really destroy the vertical, bureaucratic flow of work but simply requires that line organizations talk to one another horizontally so work will be accomplished more smoothly throughout the organization. The vertical flow of work is the responsibility of line managers. The horizontal flow of work is the responsibility of project managers, and their primary effort is to communicate and coordinate activities horizontally between the line organizations. (Kerzner, 1979) [12]

1.4. Agile Project Management

Agile development refers to any development process that is aligned with the concepts of the Agile Manifesto. The Manifesto was developed by a group fourteen leading figures in the software industry, and reflects their experience of what approaches do and do not work for software development (cPrime.com).

Individuals and interactions		processes and tools
Working [product]		comprehensive documentation
Customer collaboration	over	contract negotiation
Responding to change		following a plan

That is, while there is value in the items on the right, we value the items on the left more. (Beck et al, 2011) [1]

The author has chosen to borrow concepts from this family of empirical project management specifically because the workflow and the reality of the way business is done in regards to ETO projects in Tech Group fits so well with the main postulates of the manifesto drafted by the software developers in the late 80's and early 90's. Since that time many methods have evolved to give a more concrete shape to the principles that were highlighted in the first brief document – one of the most notable examples being “scrum”.

Scrum focuses on small, cross-functional, self-organizing teams, requiring team members to split the work into a list of small, concrete deliverables, then set priorities and estimate the relative effort of each item. Scrum is based on short fixed-length iterations (usually 1–4 weeks), with potentially shippable code demonstrated after each iteration, and use retrospective to optimize the process after each iteration. (Moksony, 2014) [14]

The workflow of a scrum project usually supposes a thorough “sprint planning meeting” where the project team decide on priority and the difficulty of the deliverables – constituents of the overall project – to be included in the next iteration of the design, execution and testing called the “sprint”. A project is made up of several sprints. During the sprint the team holds daily quarter hour meetings, also referred to as stand-up meetings, during which they communicate what they were working on yesterday, what they will work on today and what impedes them. The team lacks a de jure project manager, the responsibilities of whom are by canon internalized within the cross-disciplinary self-governing team.

There are, however, two extra roles known as the scrum master and the product owner required to help run the process. The product owner is the one responsible for maximizing return on investment – he has the final say regarding any disputes on interpreting the specification of the project. It is good if the product owner can be the actual client, but usually this role is internalized within the company, at times someone formerly used to the role of the project manager. The responsibility of the scrum master is to see that everyone adheres to the customs of the process and to shield its participants from externalities; the scrum master is also the one responsible for refining the main piece of documentation known as the “sprint product backlog”. The scrum master, however, has no authority over the team but must merely provide it with tools to make it function well.

The sprint is completed when the time allotted for it comes to an end. All ends must be tied up by the developers and the testers to produce a partial working iteration of the final product. After a sprint is completed a “sprint review meeting” is held where the team reflects on the iteration of the product delivered and on how the process of that particular sprint went. After this a new sprint planning meeting is held and the sprint cycle repeats itself until a sufficient amount of value has been delivered to the customer to count the project as completed.

Now there are several major differences between software and hardware that would not allow a manufacturing company to adopt the scrum process in its entirety – most notably the fact that software build times are measured in minutes, while hardware is built within weeks – therefore the temporal offset between the design and the potential shippable and tested iteration of the product is noticeably large and no immediate feedback can be available after a design iteration is over. Although limited, however, this possibility to go ahead with building and testing deliverables in an iterative fashion instead of waiting for the whole of the design process to complete before moving on may have merit. Most of the time, however, we must concede that the judgment on the goodness of design has to be made on the basis of the theoretical design – drawings and calculations – not its physical manifestation. What we can, however, observe is that this review process is given special attention – we must treat any review with due diligence. Bringing in the people from production to the review meetings is the least we can do before deciding a design of a deliverable of a project to be completed. Additionally opinions of assembly workers in regards to the review of a 3d model of a design may have significant value as well. On the whole we must use imagination and insight to discuss the design – and note potential future

problems. Only after this can the design can be considered “done” and can later be manufactured, built and tested in its entirety.

Several major differences to contrast APM to the PMBOK advised methodology are noted concisely in the quote by Alexander Lesnevsky below which was originally published as a part of 2007 PMI Global Congress Proceedings in Budapest:

“Requirements are baselined at a high level” (DSDM Consortium, 2007) “Welcome changing requirements, even late in development. Agile process harness change for the customer's competitive advantage” (Larman, 2004, p28); “Encourage exploration” (Highsmith, 2004, p27); “All changes during development are reversible” (DSDM Consortium, 2007) – These principles show quite different approach to project scope as compared to PMBOK which reads: “The approved detailed project scope statement and its associated WBS and WBS dictionary are the scope baseline for the project” (PMI, 2004, p104). It could be understood as if the scope is frozen. The scope in agile projects is very often defined as Feature Breakdown Structure whereas WBS is defined only for the next iteration at a WBS level, which is pretty fine grained. The suggestion here is to emphasize that the scope can be defined on a high level in order to embrace and not to prevent future changes. (Lesnevsky, 2007) [13]

The author of the above quote takes a special attention to the way the scope of the project can potentially be handled. This is a point that the author of this thesis would like to emphasize as well, although it is completely rational to try and fix the scope of the project as much as possible during its start – it is not always possible to do so in practice. When providing a wide array of customers with a flexible scope of services – it is clear that the company cannot foresee everything before the onset of a project. Some problems must be solved during the project execution stage and the solutions to these problems may shift its scope, sometimes rather considerably. A design process suitable for a company wishing to stay flexible must therefore fully accommodate the possibility of scope changes as a normal component of its design process.

1.5. Scrum and Manufacturing

Waterfall methodologies in large companies are in most cases deeply embedded in processes which link to other departments and which are outlined in various guidelines and depicted in IT tools. The attempt to create a completely new methodology with new processes which fit perfectly with the methodology will in most cases fail. As nobody is willing to do all the changes that would be needed, the consolidation of various outputs for reporting reasons would be difficult and the roles available would be different from those needed for agile. Therefore, we have to abandon the dream of using “pure” Scrum as an example. It is more critical to integrate our agile approach into the existing methodology, so that it has only minimal impact on all existing processes. (Wyss, 2014) [23]

As the author of the above quote highlights – we must be realistic in our goals of integrating APM methods into the existing company structure – simply copying approaches from the IT industry to manufacturing will clearly bring more harm than good to the organization. But as was noted by the author of this thesis – there are several places where APM-like approaches have naturally evolved within the company structure for handling ETO projects in spite of the linear approaches that are natural for the serial production paradigm which the company also handles. These will be the points on which the author will try to concentrate the effort of lifting systemic constraints imposed by linear methodologies and augment the quality versus time criteria of products and processes. As noted by the authors of the original Agile manifesto:

Scrum is founded on empirical process control theory, or empiricism. Empiricism asserts that knowledge comes from experience and making decisions based on what is known. Scrum employs an iterative, incremental approach to optimize predictability and control risk. Three pillars uphold every implementation of empirical process control: transparency, inspection, and adaptation. (Schwaber and Sutherland, 2013) [20]

In tune with the iterative methodology of scrum and the observed activity of the actual design department of the company when handling ETO projects the author will focus on outlining a flexible plan of action rather than drafting a strict linear process which will be of little use in practice. Allowances will be made for contingencies and plans of action will be available to handle events that usually occur during the design of an ETO project. This outline will encompass what has come to be considered best practice in the company. It is important that the stakeholders of the project understand the routes they must take in order

to deal with a problem or an event in a manner that has been empirically proven to produce good results. How exactly one or another project unfolds will be the product of the actual requirements of that project and the expertise of the company at that given time.

The author, backed by the interviews with the employees of the company and his own observations, supposes that in the world of mechanical and electrical engineering daily scrum meetings will not produce much value. The evolution of deliverables or designs is relatively slow. So to make any useful assessments on what is going with the project a slower pace of review is required. This pace of review can vary with the project size and complexity – with larger projects having more interdependent deliverables that need to be based on common ground and more complex projects benefiting from the peer-review opportunity provided by these meetings. As such the author will propose to classify the project according to its complexity based on the variables normally available or deduced with relatively little cost at the start of each given project. The project will then receive a benchmark score and based on that – the amount of “stand-up” meetings and the frequency of updating the project status using the work breakdown and burn down charts will be decided.

The projects the company takes on usually have a total duration of about 12 to 16 weeks –which leaves around four to six weeks for the primary design process to complete – after which the design should be ready for manufacturing. Due to this duration the amount of sprints will in most cases be equal to one – but this can be refined for more complex projects where the amount and the qualities of the deliverables clearly hint at the benefits of decoupling certain deliverables in time. A higher amount of sprint planning meetings interim will be viewed as a luxury if not waste due to their overhead alternative cost. Additionally as the projects differ in their scope notably, all meetings will be treated as generic: being divided only by their duration – with shorter stand-up meetings and longer design review meetings – what exactly goes on at meetings is whatever the situation requires. Similarly a “planning meeting” will simply be the first design review meeting the team hold at the beginning of the primary design stage of any project.

1.6. Uncertainty of the design process

For our purposes the author sees it necessary to divide the scope of uncertainty inherent in handling NPD ETO projects. The author will base the division on the terminology famously used in the US Department of Defense press conference by Donald Rumsfeld in regards to the issue of WMD in Iraq (the quality of the abstract idea here being taken out of context from the number of preemptively terminated lives which may have been provoked by the underlying agenda of the speaker):

Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones. (Rumsfeld, 2002)

Not only do these “Unknown unknowns” provide difficulties to the management of “free countries” but indeed to the management of any projects, especially those with a notable cone of uncertainty such as those related to NPD. When designing projects the designers basically produce an imaginary model to support a physical process they wish to introduce into the real world. The accuracy of this model is subject to the constraints of the competence of the designers as well as the time and budget constraints of the project and the complexity of the underlying physical processes it relies on. There are in this regard:

- The known knowns: the areas in which the company and its engineers have experience and have developed level of know-how;
- The known unknowns: areas where the expertise of the company is limited yet it is willing to take a calculated risk to try and implement them to the best of its abilities e.g. never before done processes, never before used components;
- And the unknown unknowns: problems which come up during testing or commissioning which were completely unaccounted for in the primary design process for one reason or another.

Project bound design-related uncertainty and its practical causes	
Unknown unknowns <ul style="list-style-type: none"> • Complex interlaying of physical processes • Oversight due to lack of critique and review 	Known unknowns <ul style="list-style-type: none"> • Lack of company experience • Complexity of physical processes

Figure 8 – Project bound design-related uncertainty

It is an inevitability that some complexity-related unknown unknowns will invariably come up at the testing or commissioning stages and will need to be dealt with in an empirical experimental manner. Other practical unknown unknowns are of more interest to us: these are the things that were unaccounted for in the design of the project but could have been at the very least acknowledged. Once noticed – these problems, depending on their complexity, could be moved to the known unknowns category and handled with care or at times even judged to be known knowns and dealt with in due time and fashion.

As such good design for the purposes of this thesis constitutes a method which helps us better deal with uncertainties throughout the project – to spot them and to handle them more efficiently. Good design is not limited in time only to the activities of designing a solution for production but – to be effective – must accompany all of the following stages:

- Price offer stage
- Primary pre-production design stage
- Factory acceptance testing
- Commissioning support and fixes when the line is installed at the client’s premises

To this end the known unknowns should be tackled more aggressively and the presence of the unknown unknowns must be acknowledged as a given. The latter in their turn must be searched for and reduced to known unknowns. Both of the unknowns must be addressed as early as economically possible. For some of these unknowns may in fact pose an insurmountable obstacle to the execution of the project within its supposed budget.

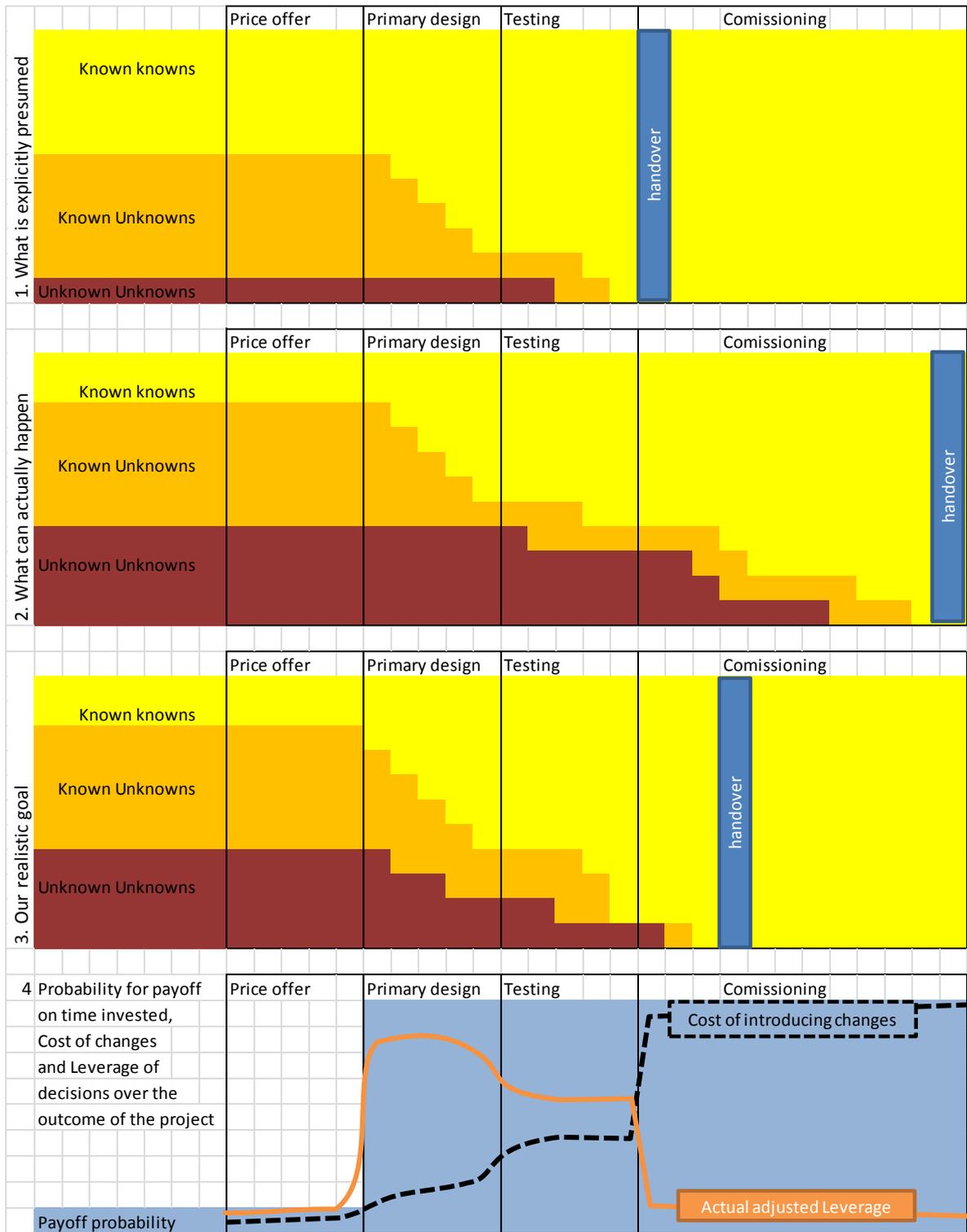


Figure 9 – Uncertainty and the actual adjusted leverage of decisions made at varying design stages

The figure above illustrates what the author believes in regards to the general form of uncertainties faced by the company throughout most projects. The author also believes that the methods currently employed at the company treat uncertainty with undue respect in regards to their actual magnitude. In reality some projects can end up costing the company

significant resources due to the belief, that there is little uncertainty inherent to them and that if there is – it is mostly of the known unknown type. In general “Figure 9 – Uncertainty and the actual adjusted leverage of decisions made at varying design stages” communicates what the author means when using the phrase „good design process“ within the bounds of this thesis. A good design process is one that:

1. Reflects reality.
2. Acknowledges and disarms uncertainties as soon as possible.

Such a design process would lower the overall project cost and improve customer satisfaction through less rework and timely handovers respectively. Granted we cannot hope to get everything right at the design stage if the project is sufficiently complex – we must, however, employ tools that force as much due diligence onto the primary design process as possible. These tools must be easy to use and extend the company’s overhead costs as little as possible. In the plan of action chosen by the author, the extra cost that may be incurred will be made to serve the strategic goals of the company. The main ideas of the author for the timely reduction of the harmful unknowns in the project are rather simple:

- 2A. Improve the effective cooperation between the stakeholders of the project.
- 2B. Improve the effective retainment and availability of experience and know-how from prior projects.
- 2C. Focus on decoupled deliverables of the project so as to receive more rapid feedback on the suitability of the adopted design.

Effective cooperation and transparency are thus a primary concern, This concept is not limited to just the design and engineering department – promotion of open cross-departmental cooperation with purchasing and manufacturing in the form of both information worker feedback and manager input is a must to guarantee the health of the product and the project. Not to be forgotten is the input of the most influential stakeholder of the project – the client. Our goal here is neither to minimize the cost of design nor to improve some predefined quality of the products in a given direction. The goal first and foremost is to handle uncertainty in a way that would consistently provide us with designs that work and provide the customer with maximum value on time and within the predefined budget project after project.

1.7. Promotion of organizational learning

A study based on 44 interviews of 19 project-based organizations, within a range of different industries, Keegan and Turner (2001, p. 89), found that all organizations, “without exception,” had lessons-learned policies in place to capture learning from projects once completed; yet, even with established policies, lessons learned rarely took place. So why does learning not happen? Based on a survey in which the respondents were asked to express their own opinion concerning, for example, a climate supportive of learning, tools for learning, and exchange of knowledge, Gieskes and ten Broeke (2000) pointed out that project management tools are not used to their full extent to benefit learning. Empirical work on learning in project management research indicates a need for cross-project learning (Julian, 2008) or project-to-project learning (Goffin et al., 2010; Koners & Goffin, 2007). This indicates a need to have a holistic and more systematic perspective that supports learning (i.e., development of an organizational-wide project learning process). (Chronéer, 2015) [4]

So how do we manage to actually implement something that everyone intuitively knows should exist, yet seems is practically difficult to achieve? The answer to this question, the author supposes, lies in finding the right form adopted for the retention of learning. For the informational function of the endeavor is already self-evident. At the moment in its set of standard documents and procedures Tech Group has forms for documenting the outcomes and deviations of project based activity. These forms are very detailed and classified by type within the bounds of every project, yet the problem with them is, from the standpoint of the author, is exactly that – too much data and not enough information. What is needed from an effective organizational learning system is the following:

1. Accessibility – all information should be easily searchable, intuitively assessable by humans and cross-linked to minimize the effort of traversing it.
2. Brevity – the historic information should reflect only the most important general principles that should be remembered.
3. Holism – information should cut across the company’s history and not be compartmentalized by projects.

Based on these assumptions the author will argue for the adoption of historic pivot tables accumulating general information on the execution of every project to be used for

future benchmarking and difficulty evaluation of new project. A periodically refined brief checklist which should aid the design the department in avoiding its historically most popular and notable mistakes. The goal of the author is to transfer the documentation of issues that are worth remembering onto a platform voted by humanity as the most suitable tool for this purpose, which at the time of writing remains a wiki resource. This resource would become the company's internal go-to encyclopedia when devising new processes, doing calculations and research and engineering new machines. This last part in turn requires:

4. Motivation – the active involvement of the stakeholders in the learning process

Based on conversations, observations and “lessons learned” documentation which can be found in project folders on the company's server, the author made the conclusion that design and engineering team is genuinely interested in participating in such an effort.

1.8. Adaptation of critical chain project management principles

At the moment task duration and the preliminary work break-down structure (WBS) for projects at Tech Group are mainly based on the sales manager estimates. These estimates are in turn on his experience and the feedback from previous projects and the design staff. The estimates are used as guideposts for carrying out the actual project and judge its economic success based on under/over analysis of the actual hours spent on the project versus the estimated figure, when relatively little was known about the actual difficulty of the tasks at hand.

This preliminary estimation already includes a buffer for the uncertainty related with that particular task within its duration. As part of the improved design process – the author wishes to advocate that these normative task durations be pretty much ignored during the design stage. The participants of the project should be advertised only the deadlines proposed by the project schedule, these deadlines in turn should be based on lower duration estimates and an overall project buffer should be used at the end of the project to compensate and accumulate the uncertainty from every individual task. This is due to psychological behavioral patterns of individuals often cited by proponents of critical chain project management (CCPM).

The more safety in a task the more there is a tendency to behave in the following ways:

- Not starting the task until the last moment (Student Syndrome)
- Delaying (or pacing) completion of the task (Parkinson's Law)
- Cherry picking tasks (Goldratt, 2014) [10]

It is proposed that this partial adaptation of CCPM principles for creating project buffers will help better manage the temporal uncertainty of the design of the project. Furthermore, resources such as engineers experienced in a particular segment of technology are more limited within the company – while some parts of the deliverables do not require such expertise. Tasks such as finishing parts and assembly drawings – can be lifted onto any employee of the design department, without the quality of the deliverable suffering any significant penalties. Furthermore the expertise of these more experienced engineers may be required in other projects, whose timeframes are also limited. As such breaking down the general deliverables of the project with regard to optimal loading of critical resources in the design department of the company is a must. To this end steps are taken within the company in practice. But the theoretical framework behind this work does not accommodate this reality. The tasks are usually handled in one large chunk which a single engineer has to see through from the beginning – producing a concept for the solution – to the end – making tidy assembly drawings and refining BOMs. So the author proposes the further breakdown of deliverables into components shown in the following figure. Whether these sub-deliverables are in fact handled by the same individual or several – is up to the loading of the design department across varying projects and is for the stakeholders of the projects to decide – the main idea is to change the conception of the stakeholders in regards to the manner that deliverables have to be completed. This will also aid the company to go ahead with purchasing and assembling components and machines quicker – which would leave more time for testing and receiving feedback on the implemented designs. Further concentration of the expert engineer on solving the technological problem at hand instead of switching between tasks of designing and drafting should provide him with more energy to use on adding value to the project.

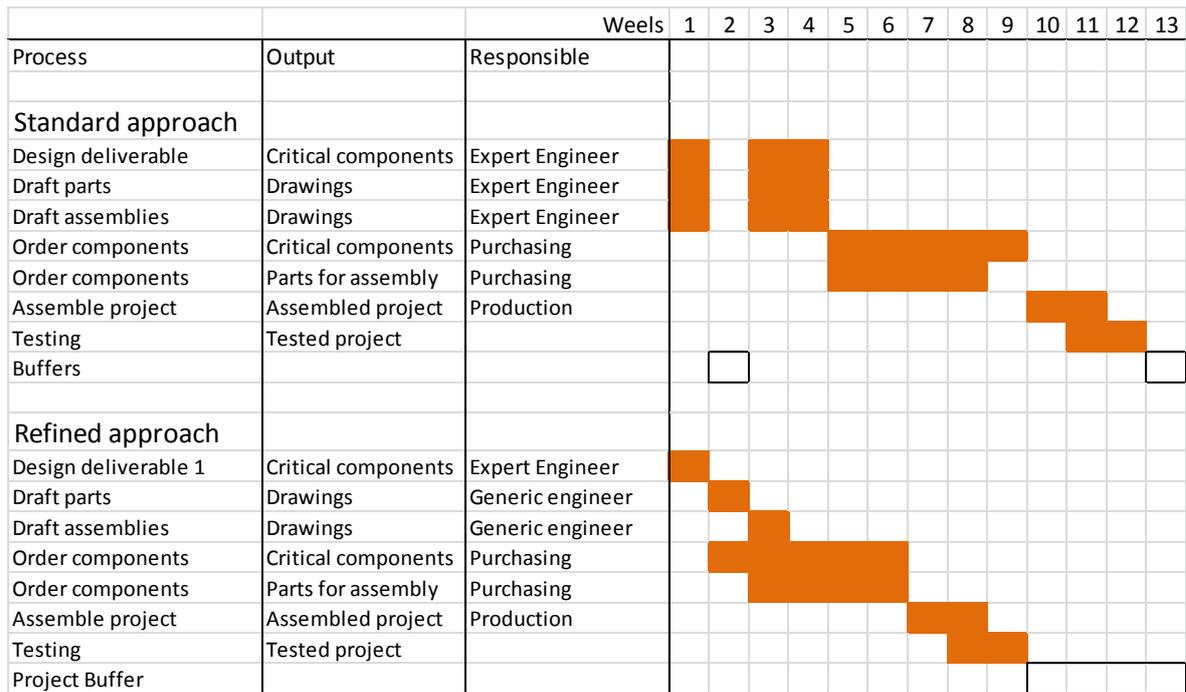


Figure 10 - Refined deliverable breakdown and project buffers

Taking into account that critical project components such as build to order motors and actuators as well as other specific standard components can have lead times of up to 5 weeks whereas most manufacturable parts can be ordered from local suppliers within 2 to 4 weeks – this tactic can allow us to double the project buffer which can be further used on dealing with contingencies.

Furthermore it is not our direct goal to shorten total ETO project durations, as the usual 12 weeks deadline from customer confirmation, usually adopted for the execution of small to medium size projects is competitive. But we would like to leave more time for testing and gaining useful feedback from built machines to improve the final quality of the projects visible to the customer and reduce possible budget overruns which the company incurs, when fixes need to be made to the already commissioned machines at the customer’s premises. Here we can be aided by a study cited below:

How much shorter could project schedules be if team members were not fearful of using most likely estimates? If team members are asked to provide a task estimate, are they inclined to provide one that is 50% likely or one that is 95% likely? Most project team members would provide the 95% likely estimate (Walker, 2010). The figure below illustrates two probability curves. The bell-shaped curve with a long tail represents the probability density of task duration. The “s” shaped curve is the cumulative probability. A

project task that is 95% likely is typically two or more times the duration estimate of the 50% likely estimate.

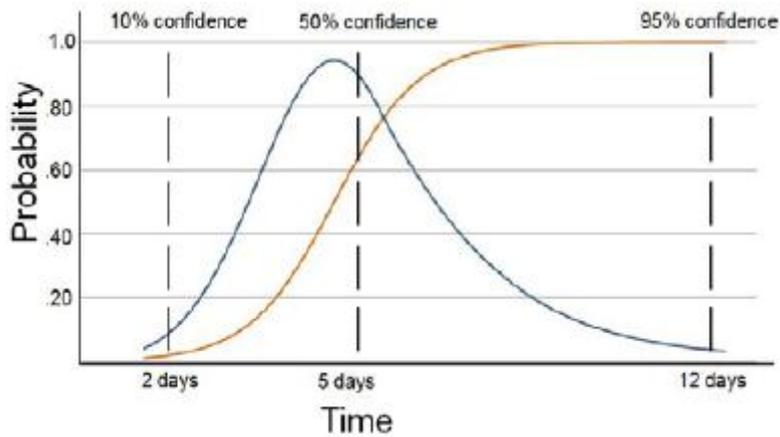


Figure 11 – Probability of task duration (Cooper, 2013) [5]

When estimating task durations – it was noted within the company that 95% confidence estimates are indeed used, as such the normative time advertised to the project stakeholders will indeed be cut in half in the future. The remaining time will be added to the project buffer to be used up by the tasks themselves as well as other contingencies as needed.

2. Company Background

2.1. Tech Group as a company

Tech Group is a manufacturing company operating in Estonia. It is a medium-size enterprise and has about 70 employees. The range of the company's activities is wide. Over its 10 year history the company has produced products ranging from motorcycle mufflers to fully automated ETO production lines. At the moment the company concentrates on being a reliable subcontractor to a few key customers as well as handling the design and execution of custom technological solutions for a wide range of industries. Below is a diagram illustrating the main areas of business the company is involved in:

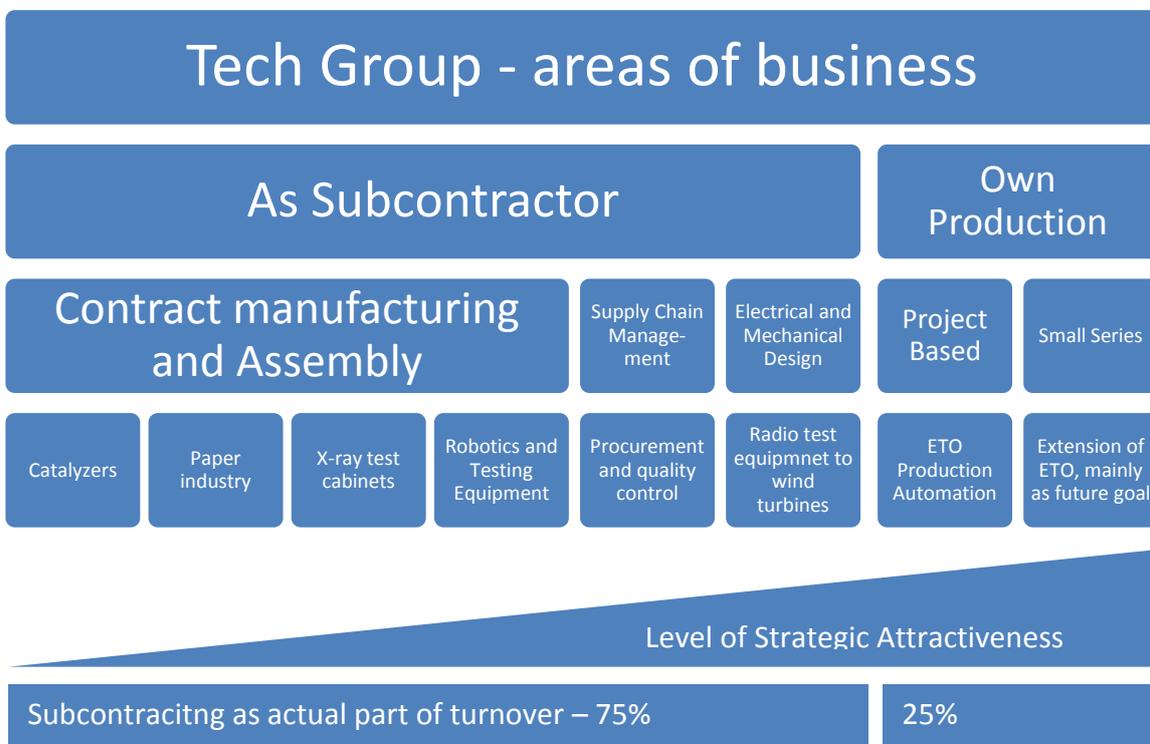


Figure 12 – Areas of business of Tech Group and their level of attractiveness for strategic development

As one moves from left to right the reliance on the internal competence in the execution of the tasks grows – as does the share of the risks the company takes on – so too grows the profit potential and the prestige associated with handling that area of business. The areas towards the left are somewhat simpler for the company to handle – the main focus for reaching success in them is improving the efficiency of operations and maintaining a high level of quality control over production. There is some room for improvement in these areas, but the potential for gain here is marginal unless one wishes to

significantly increase the volume of production. Increasing the size of the company to capitalize on the marginal gains in operational efficiency – increases the overall risk of failure – considering the magnitude of the potentially tied up capital – with new investment and upkeep costs needed to serve a presently volatile outside market.

What is clear from the weekly sales meetings and the testimonies of company management is that the main goal it wishes to actually pursue is the augmentation of its own production base. The company wants to increase its in-house competence in producing design which is new to the company. Following this it is important to focus on marketing to scale the sales of once executed projects and their constituent machines and move towards small series production based on in-house design.

Tech Group has naturally evolved a strong matrix structure which supports the execution of unique projects quite well. The company is ISO 9001:2008 certified, but as this standard does not cover any project management issues – the postulates that are in place for handling projects are derived from experience and are rather brief as will be discussed in further chapters.

2.2. Goals of Tech Group

The idea that organizations should focus their energies on the creation of shareholder value is sometimes credited to a 1981 speech given by then CEO of General Electric (Jack Welch). In that speech he extolled the importance of seeing shareholders as owners and the need to focus on creation of “shareholder value”. Welch’s speech is sometimes credited with triggering the short-term share-price oriented form of management that the IBM staff worried about. Jack Welch himself recognized how the shareholder value mantra could corrupt the core values of an organization and in 2009 he backtracked on his earlier speech saying that “On the face of it, shareholder value is the dumbest idea in the world,” ... “Shareholder value is a result, not a strategy... Your main constituencies are your employees, your customers and your products.” (Goatham, 2015) [9]

The author’s approach takes it as a given that the goals of the company are not directly financial in nature – there are few enterprises exempt from the Finance, Insurance and Real-estate (FIRE) sectors whose goals are just about the bottom line. Even within the FIRE sector enterprises may have imperative goals that clearly go beyond the scope of increasing shareholder value. However, it is difficult to state the exact goals of any enterprise in such a manner as to analyze the starting conditions, the results and measure

the progress on the rout hitherto – as such financial KPIs may be used as a crutch for the assessment of the well-being of the company. It must, however, not be forgotten that the performance indicators should not be looked at in a vacuum – other information about the company spread among the company stakeholders – its management, its employees and its customers – is what gives true context for the financial KPIs which we in turn can easily track over time.

For simplicity, however, we will use some straightforward economic indicators – the context for which is provided by the whole body of this thesis. For this purpose the author has compiled a chart illustrating the desired directions of movement of performance indicators of the company in relation to their figures measured in 2014. The basis for this is the information from the “Goals of Activity” documents which are drafted and corrected on a yearly basis by the company. As such this information outlines the general consensus opinion of the management in relation to the path the company should take in the future:

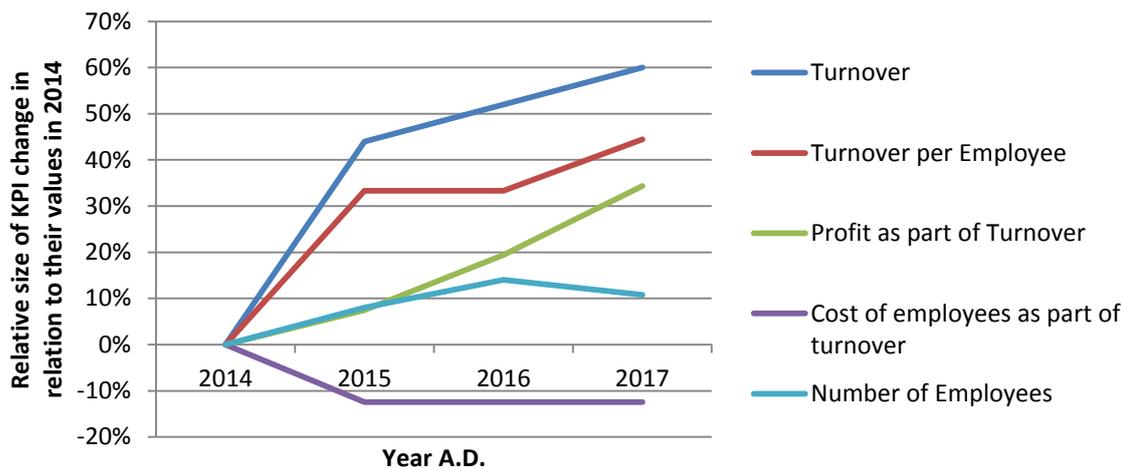


Figure 13 – Goals of Tech Group (in % of change in relation to figures of 2014)

As one can see from the Figure above – it is in the interest of the company to increase turnover and its operating efficiency while keeping the size of the company relatively stable. The increase in turnover per employee can be achieved by increasing the efficiency of the production processes and optimizing the loading of the company’s resources. These factors alone, however, cannot account for a 40% increase in turnover per employee over a 4 year period. This is especially true if we consider that the manufacturing capabilities of the company are limited – the main areas of manufacturing at the company are mechatronic assembly and welding with facilities that are currently suited to serve an established subcontracting manufacturing base. As such there is little slack in the

manufacturing processes which could be optimized to yield the extra returns. Another way to increase turnover would be to handle more of the “supply chain management” projects – forwarding relatively simple assemblies and parts from other suppliers directly to customers. The execution of this strategy, however, is difficult to control internally – concentrating the company’s effort on influencing the buying behavior of external stakeholders is a riskier bet.

Strategies to increase Turnover per employee		
<p>Increase overall efficiency of operations</p> <ul style="list-style-type: none"> • Only marginal gains available here without significantly growing the enterprise 	<p>Increase amount of engineering / SCM projects</p> <ul style="list-style-type: none"> • Execution of strategy relies on influencing actions of external stakeholders 	<p>Focus on improving own production</p> <ul style="list-style-type: none"> • A lot of room for growth and profit potential available here

Figure 14 – Strategies for increasing turnover per employee

The more realistic and internally controllable ways to achieve the desired amount of increase in turnover per employee are thus to focus on producing products based on in/house design, and here there are several paths the company may wish to take:

- 1) To improve the execution of higher-risk higher-margin ETO projects which are taken up by the company;
- 2) Expand sales of own products which were already executed as stand-alone projects into small-series production.

The second option has the attractive benefit of reducing risk per every executed order while the margins are higher than when doing sub-contracting assembly work based on other companies’ designs. The downside is the highly competitive market in the areas where standard automation solutions have many specialized companies willing to provide them. This option is definitely a strategic goal that the company is looking to seize if both internal factors and market circumstances are right. A point currently omitted from the explicit future financial plans of the company is increasing the efficiency of interactions with the outside environment, i.e. promotion and marketing costs. It is, however, discussed

internally at meetings and certain steps are taken towards that end – indeed this is the right way forward for the company, but is not within the scope of this thesis.

This far-reaching strategy, however, is completely reliant on the in-house competence and expertise in the areas of automation design. The way to confidently move towards success in small-series production in the future is thus, in any case, to take special focus on project-based activity in the present: One must grow the professional competence of the company in the area of designing complex custom projects.

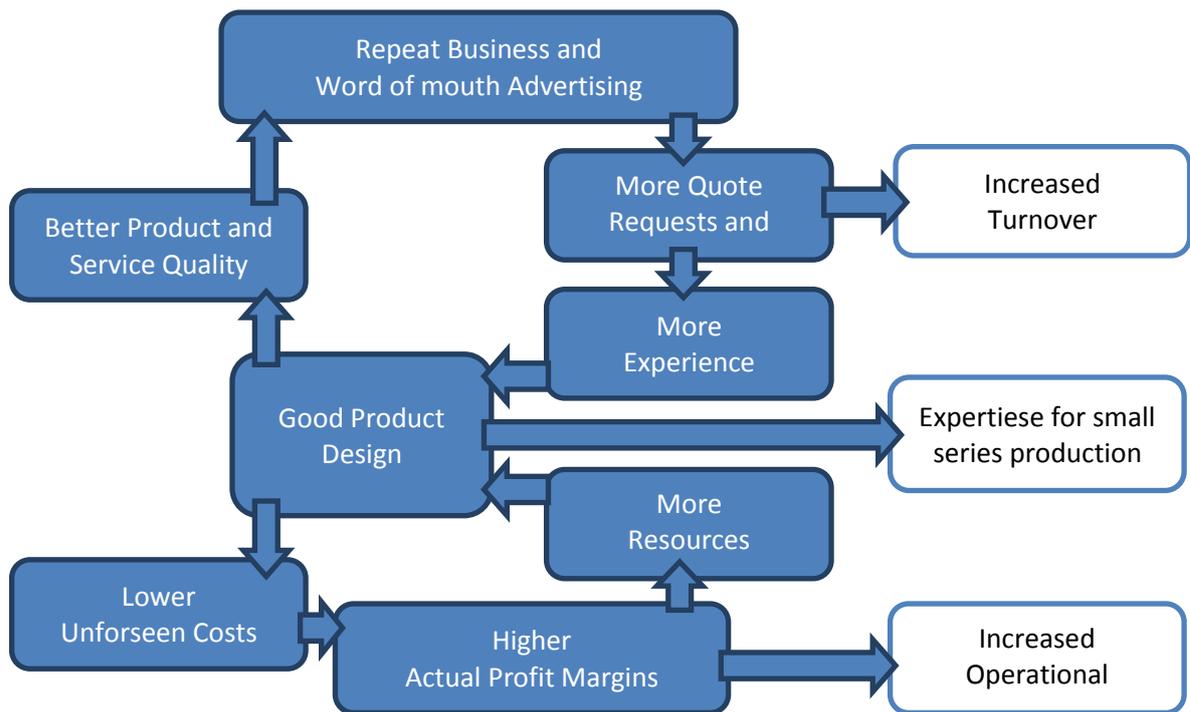


Figure 15 – Positive feedback loop attainable through the good design of ETO products

As one can see from the figure above – the quality of design can be both an engine and a brake for increasing the operational efficiency and turnover of the company. These financial KPIs, however, may be viewed simply as a byproduct of growing internal competence. In total there are three main “by-products” of Good Design which the author wishes to highlight as being beneficial to the company:

1. Increased turnover potential due to better reputation
2. Increased expertise that can help scale into small series production
3. Increased operational efficiency due to lower unforeseen project execution costs

What is of utmost importance here is that all of these “by-products” are in tune with the strategic goals of the company. As such improving the quality of design can with confidence be viewed as a powerful lever to steer the company in the direction it wants to move in.

Furthermore the marketing plan of Tech Group for the year of writing the thesis includes clauses for positioning Tech Group as a “Customer-focused Company” with a strategic position of “All services from one supplier – from project to handover” and “Highest quality at the stated price”. Both of these maxims imply the importance of producing high quality designs that satisfy the customer.

Good product design will improve both the quality criteria of the end products as well as facilitate a higher quality of the services provided by the company, with less on-site adjustments and rework. Less rework – means less unforeseen cost for the company and less cost overall, which, by definition, translates into higher profit margins. The better the product and service that the customer receives – the higher the company`s chances for repeat business with the same customer as well as the reputation of the company through word of mouth advertising. This in turn lead should lead to an increase in the amount of projects quoted and potentially executed by the company – the byproduct of this being increased turnover. The increase in the amount of projects being handled even at price quote stages will help grow the internal competence of the design department of the company, its members and the quality its supporting processes. More profit which is not lost as redesign and rework from the projects executed may further flow improving the staffing and the work environment of the design department when the need arises.

The next question thus becomes self-evident: what is this „Good Product Design” that is worth pursuing, and how do we attain it consistently?

2.3. Good Product Design

Lifting weights increases your muscle mass. In the past they used to say that weight lifting caused the 'micro-tearing of muscles,' with subsequent healing and increase in size. Today some people discuss hormonal signaling or genetic mechanisms, tomorrow they will discuss something else. But the effect has held forever and will continue to do so. (Taleb, 2012) [22]

In the end it is the customer who decides whether the project was a success or a failure based on the apparent results. What internal processes were used to achieve that result is by definition irrelevant. But for the practical purpose of running a company a set of theories should be chosen as a basis for structuring the design process in hopes of meeting customer expectations. These theories should be judged and adjusted on the basis of the results that they produce.

As such the quality of design will be judged on a historic basis – the causes of flaws or shortcomings of its projects will be deduced based on the testimonies and experience of the people involved in the projects: designers, assembly workers, programmers and project managers (the author included). Searching for the cause of failure in our case by no means implies tracing the fault of the problem towards some individual or department; rather it involves extrapolating failures to a systemic cause for their occurrence.

How much documentation supported the final solution? How accurate or detailed were the Gant charts that were employed? What fancy acronyms were used to justify the structure of the decision making process? The answers to these questions may show notable positive correlations with success in the repeat-business world of serial manufacturing or much of civil construction – but as the “newness” of the project increases from the standpoint of the company executing the project – the strength of these correlations slowly fizzles away. Research, conducted in collaboration with the University of Oxford, suggests that half of all large IT projects—defined as those with initial price tags exceeding \$15 million—massively blow their budgets. On average, large IT projects run 45 percent over budget and 7 percent over time, while delivering 56 percent less value than predicted. Software projects run the highest risk of cost and schedule overruns (Bloch et al, 2012) [3]

It would be safe to presume that most such high-caliber projects were indeed managed based on industry-standard and expert-approved project management systems. Getting an innovative project right, however, requires more than putting A before B and B before C and controlling the quality of the outputs along the way. The author will take as an axiom that it requires the emulation of the human creative process across an organization involved with the project. The organization as a whole must have the capacity to experiment and adjust its course based on arbitrary intermediate results observed during the execution of any project as well as the lifetime of the company as a whole.

The yearly turnover of Tech Group is a fair bit south of the 15 million figure used as a cut off point for sampling data for the above mentioned research – thus the size of the projects it handles is much smaller as well. But one trait the company does have in common with many in the software industry is that it deals with customers from a wide range of industries: from producers of windows and doors or peat to the candy, beer and liquor industries. As such there is no clearly defined corridor of competence that the company must tread – there is only a wide field of technological possibility mined with difficulties in understanding the intricacies of the finer physical processes. And only experiment in the form of the factory test and commissioning may be accepted as final judgment in regards to the quality of the design and execution of the project. Before that – there is no single authority to turn to – who would judge the designs on the computer screens and on paper to be adequate and robust or all-in-all simply “good”.

A good engineer is thus not a calculation mechanism but a scholar of history – a specific subset of history pertaining to an area he wishes to be a specialist in. Obviously, the goodness of an engineer is determined both by the width of the areas he can operate in as well as by the depth of insight he has achieved in some of these areas. The usefulness of an engineer to a company is in turn determined by how much his experience coincides with the specialization of the company.

As the author has formerly stated: due to environmental constraints, Tech Group has chosen to support clients in a wide range of industries. Often the shortcomings of such an approach become obvious. Finer details of the technical task may not be planned for or indeed even considered at the primary design stage of a given project. This leads to a situation when reassessment of the design criteria based on the experimentation during

factory testing and commissioning become necessary. What this translates into for the company is basically rework – which should be avoided as much as possible.

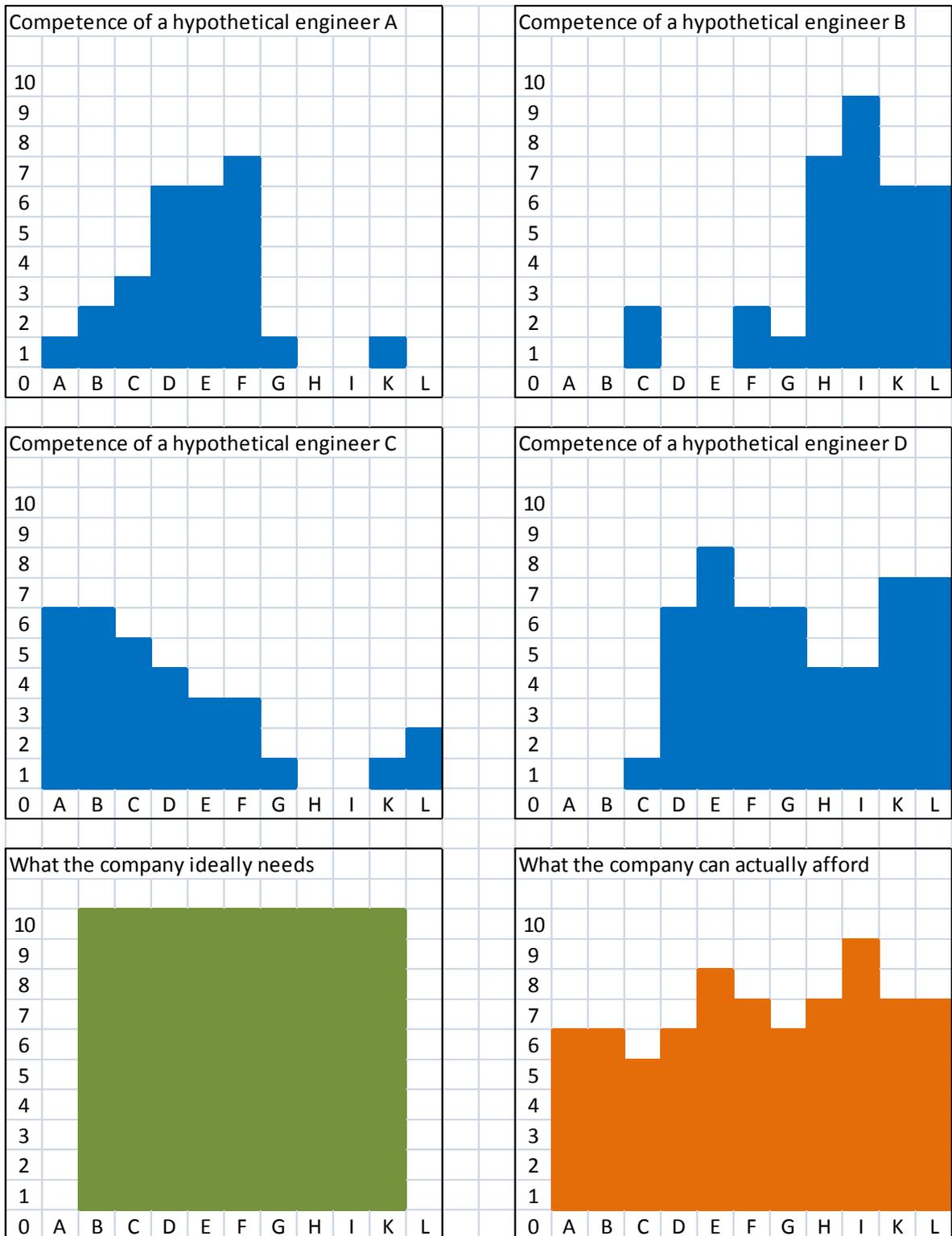


Figure 16 – Limited engineering capabilities of a company

Figure 16 – Limited engineering capabilities of a company shows a simplified illustration of the self-evident problem of a company wanting to be exceptionally competent in a wide range of engineering disciplines. Good engineers are a limited resource in our society and are themselves subject to resource constraints of time they have to develop their professional capabilities. So to fill the goal of being ideally competent in areas B through K, the company will need to spend considerable amounts of resources on staffing – in the real world this resource sink would probably overshadow the company’s turnover as well as its lifetime.

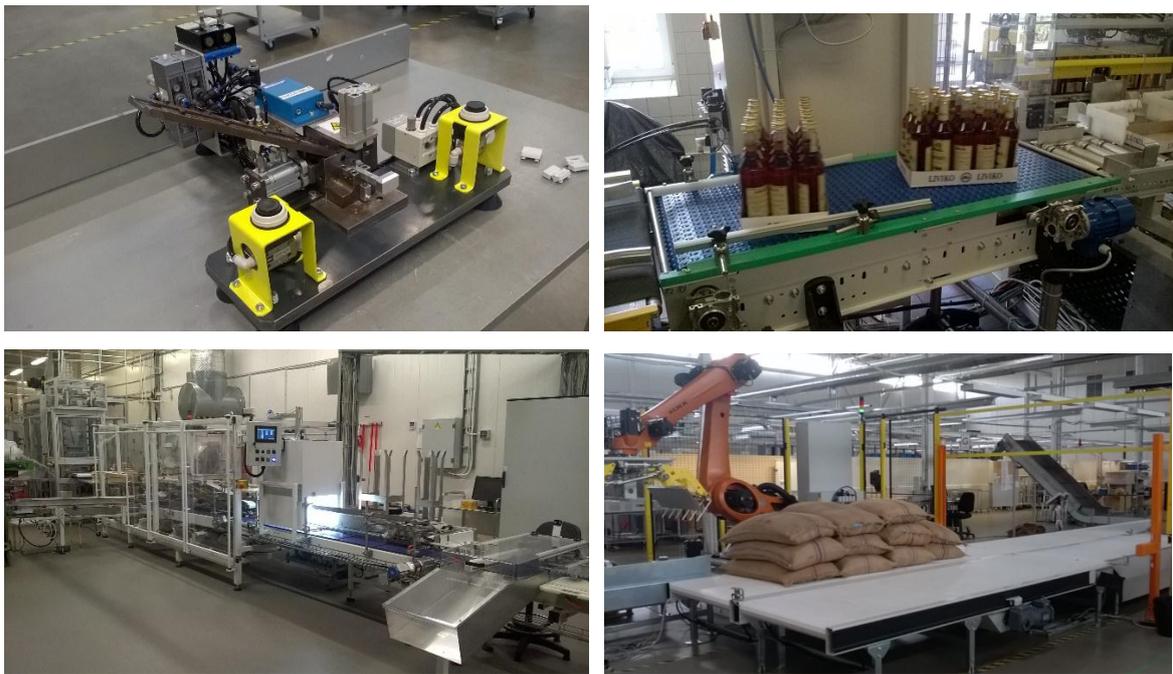


Figure 17 – Range of ETO products produced by Tech Group

If we return to terra firma it is obvious that what we want isn’t always what we have. And what Tech Group has is in the author’s subjective opinion rather good, all things considered: a compact design department staffed with self-motivated and bright engineers ready to deal with a varying range of projects. The size of the department is big enough to keep it reasonably well loaded with the preparation of price quotes and actual design of projects as well as providing support to the company’s other manufacturing activities.

Problems with design that come up at commissioning of complex projects should thus essentially be viewed not as shortcomings of individuals but in the light of realistic systemic constraints imposed on the design process. These constraints in turn should be lifted if it is economically viable to do so. One such economically viable way is to improve cooperation between individuals responsible for the design and execution of projects.

Another is to retain more useful knowledge gained during the execution of projects so as the following ones will benefit from this. In overview the author supports the following prepositions in regards to designing a good product:

1. Hire bright motivated individuals with experience or training in a required field.
2. Give them the means necessary to do their work.
3. Give them a task.
4. Provide a process framework fitting that task.

If we take points 1 through 3 as a given: “here are the people we have, with the resources we can afford working on what the market demands” – it is the provision of a proper design framework that we can try and control to get the most out of the existing system. One of the most critical aspects here being the breadth of uncertainty inherit in the tasks Tech Group deals with and subsequent acknowledgement and management of related risks of the projects.

2.4. Existing ETO process assessment

The existing design process is not really explicitly defined but constitutes a body of documents procedures and practices everyone in the company is used to employing when executing an ETO project. There are no specific tools or procedures which are exclusively aimed at the assisting the product design process as such. All of the tools here are generic and are employed throughout the customer project lifecycle. The ETO project management philosophy can be said to be outlined in the following documents which are generated as part of the new project data structure on the company sever:

- **Activity checklist**, which includes the following clauses:
 - Lock scope of project technical task and quality criteria (to what stage do we need to develop the solution);
 - Project team and task specification;
 - Project timeline specification;
 - Project execution process, stages and descriptions;
 - Allocation of resources;
 - Financial resource planning for the project;
 - Project risk estimation;
 - Project documentation volume estimation;
 - Project results estimation program (if needed).
- **Project open issues list** – a spreadsheet template for tracking issues and questions arising during the project with the following columns:
 - Date issue added;
 - Person responsible;
 - Description of issue;
 - Description of solution;
 - Date of solution.
- **Meeting memos** – a template for documenting activity at project meetings with
 - Date;
 - Participants;
 - Issues raised.

- **ProWorkFlow** – a recent addition to the company’s toolbox – a web based third-party application which allows to
 - Allocate and track design team resources by name;
 - Outline the project plan through tasks, their duration and deadlines;
 - Track schedule and resources through an illustrative Gant chart.
- **Project feedback list** – a table for summing up the direct costs incurred during the project used to summarize:
 - Material and purchasing costs;
 - Mechanical, electrical design and programming costs;
 - Assembly cost based on assembly worker timesheets;
 - Total duration of the project in weeks.
- **Lessons learned document** – although undefined in form, such documents can be usually found for larger projects and as a rule feature:
 - Problem descriptions and photos;
 - Resolutions for avoiding such missteps in the future.

It is also common practice to hold at least two meetings which involve the client during the design stage – one near the beginning of the project so that we can go over the goals and technical details of the tasks and one during the last third of the design stage – where direct input from the client may help get the finer details and workings of the design just right. There is no strict policy regarding team meetings. Explicit meetings are usually omitted for smaller projects. Alternatively explicit intra-team meetings may be said to be omitted while there are one or two project participants, but as the project reaches its final stage and electric designers, programmers or assembly workers need to be briefed on the tasks and goals of the project – special meetings are held. Larger projects are usually allocated an hour per week for meetings between the design team members right from the start.

Project scope and budget are mostly planned for at the price offer stage – the negotiations here act as guideposts for further adjustments during the actual design stage while procurement control is made with the aid of Microsoft Navision.

Based on the above we can say that the framework for managing projects is flexible and covers most of the basic points suggested by standard PM literature. Although lacking depth or cohesion in some areas the framework draws the stakeholders’ attention to critical

aspects of the project and outlines a feedback and lessons learned policy to facilitate organizational learning. If we were to make a comparison with the comprehensive project management chart from PMBOK we would end up with the picture on the following page.

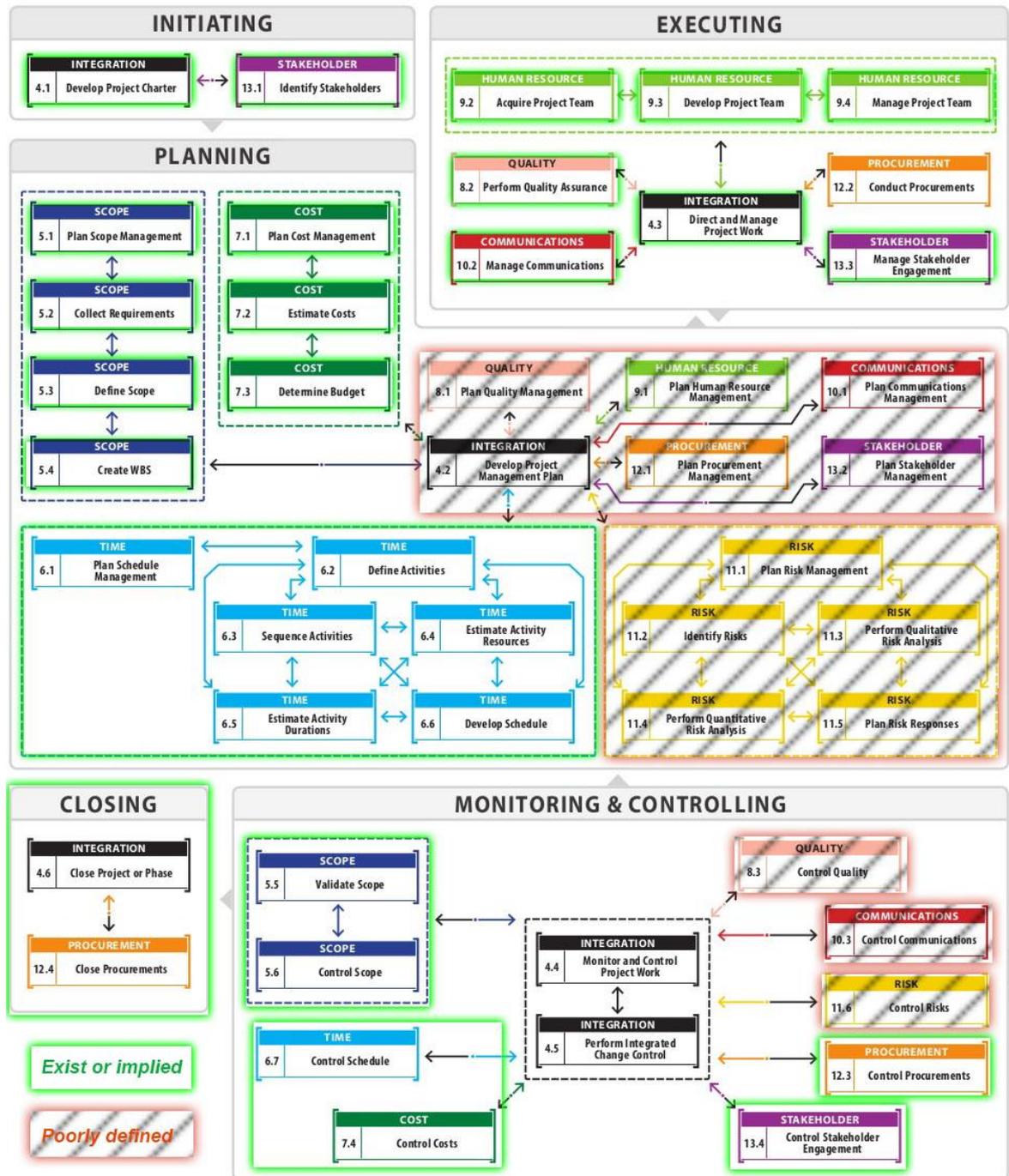


Figure 18 – Analysis of presence or absence of key PM concepts in ETO PM at Tech Group in comparison with PMBOK 5th edition proposed categories

In general the picture above looks rather good in that many of the key areas defined by trendsetters of the PM stage are exist or are at least strongly acknowledged by the existing PM process at Tech Group. However, the depth of these elements is more difficult to

gauge. The author explicitly believes that there are few methods for controlling risk in an ETO project while other areas and methods employed for them may be lacking transparency or ease of use, creating unnecessary overhead and barriers to their effective use by the project stakeholders. The author would rate the current state of affairs in these areas pertaining specifically to the design stage of the project as follows:

- Initiating – strong*
- Planning – medium
- Executing – medium
- Quality control – weak
- Risk management – weak
- Systemic coherence of tools – weak

* Although Initiating is considered strong in regards to the existence of proper tools and methods in accordance with PMBOK advice – the author believes that that model is in fact somewhat removed from the reality of executing ETO projects at Tech Group, where the set of explicit and implicit requirements for the product is in large part discovered in cooperation with the client during the product design process – not before it takes place.

It is these shortcomings that the author wishes to address with the introduction of the refined design process. The main beneficiary of these innovations will be the product design processes of larger ETO production automation projects, especially those which are novel to the company.

3. Improvement of the Product Design Process

Here the author wishes to reacquaint the reader as to how the problem of this thesis was chosen and what is the form of the solutions being proposed for the matter.

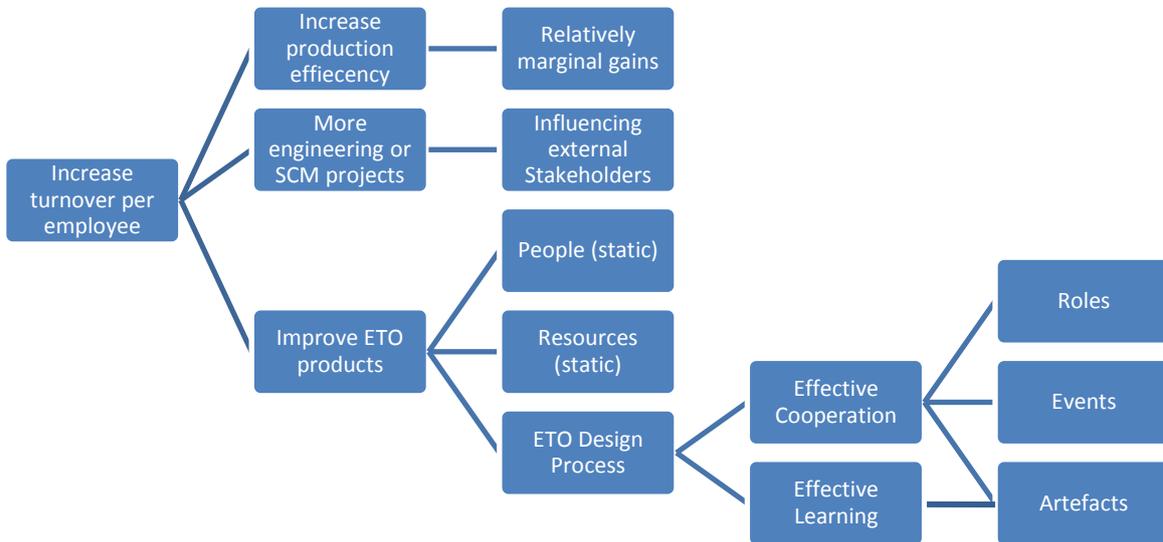


Figure 19 – Breakdown of the possible ways to increase turnover per employee by Tech Group

A process is by definition a set of steps taken in order to achieve a particular end. However, the author shall not focus on providing a predefined breakdown of a sequence of steps as such. The author will instead provide the framework which will be adaptable to most possible contingency with minimal effort on the part of the project manager and the team. The actual flow of every product’s design process will be context dependent but will be based on a set of principles defining the responsibilities and the roles of project participants, the descriptions and requirements for key events such as meetings and the documents which are used to assist with making decisions.

The refined design process should encourage project stakeholders to be

- Thorough – critical of the solutions being developed in light of varying uncertainties.
- Agile – lightweight and as free of wasteful activity as possible – any action undertaken should be focused at adding value to the customer.
- Open and transparent – cooperation, honest peer review and tools that enable transparency as to the state of the project are a must.

3.1. Improved design process – artifacts

Scrum relies on transparency. Decisions to optimize value and control risk are made based on the perceived state of the artifacts. To the extent that transparency is complete, these decisions have a sound basis. To the extent that the artifacts are incompletely transparent, these decisions can be flawed, value may diminish and risk may increase.

The Scrum Master must work with the Product Owner, Development Team, and other involved parties to understand if the artifacts are completely transparent. (Schwaber and Sutherland, 2013) [20]

The refined process will be supported by a concise body of documents aimed at keeping the team on track during the design of a project. The list of documents presented here has been refined to a minimal amount of items which take inspiration from the existing company artifacts and the items proposed by various branches of APM. With feedback from project engineers, the author deems it useful to have four constitutional artifacts that must be employed during design:

1. The project evaluation tables (PETs):
 - a. The CSI project difficulty evaluation table – based on three defining criteria of the project: Complexity, Size and level of Insourcing.
 - b. The FBT project success score table – gauging the quality of past project execution based on the criteria of Foresight, Budget and Time.
2. The Paranoid Project Checklist (PPC) – a list of problems that have been proven to historically come up during project execution and should be kept in view during the design stage.
3. The Product Backlog and Burn Down Chart – for prioritizing and dividing tasks as well as visualizing the completion of the overall design process.
4. The Tech Group Wiki – a larger set of interactive documents to be updated with information with an aim to improve the execution of future projects and as a tool for effective communication and documentation within the bounds of the current project.

3.1.1. Project evaluation tables

The author has conducted an analysis based on the projects he has dealt with at the company as well as the ones he has become knowledgeable of due to conversations with the company's staff and the research of their documentation. On this basis it was decided to produce a system that would help put any given project into historic context and assess it against the projects previously executed at the company. This assessment would give a benchmark score of the complexity of the project and would help to plan further work for a given project.

The basis for statistical research on the matter were the projects the execution of which the author supervised or witnessed first-hand. Currently there are 9 projects used as a basis for assessment, but this list is being actively updated with each new project able to add more sample points and refine the types and weights of the assessment criteria being used.

Project Dificulty Evaluation Data										
Project Number		14_018	14_088	14_023	14_106	14_121	15_018	15_023	15_068	15_042
Quoted Price		200	240	491	21	11	9	2	8	14
In-house design base		200	120	181	21	11	9	2	8	9
Adjusted Complexity score	weight	50,0	8,0	10,0	22,0	33,0	1,0	3,0	32,0	1,0
Motors and actuators	1	20	8	10	2	3	1	3	2	1
Unique products handled	10	3			2	3			3	
Project Size, Complexity and Insourcing score (SCI)										
Criteria	FBT Corr.	14_018	14_088	14_023	14_106	14_121	15_018	15_023	15_068	15_042
Complexity	-0,759	1,00	0,16	0,20	0,44	0,66	0,02	0,06	0,64	0,02
Size	0,152	1,00	1,20	2,46	0,11	0,06	0,05	0,01	0,04	0,07
Insourcing	-0,460	1,00	0,50	0,37	1,00	1,00	1,00	1,00	1,00	0,64
Project Execution Success Score (FBT)										
Measure (0...10, each)	Criteria	14_018	14_088	14_023	14_106	14_121	15_018	15_023	15_068	15_042
	Total	2	27	27	25	9	26	20	22	20
Substract 1 for every notable fix during comissioning	Foresight	0	9	8	7	5	10	7	9	7
0= Break even, 10= double the planned profit margin	Budget	2	8	10	10	4	6	4	4	5
Substract 1 for each week over project deadline	Time	0	10	9	8	0	10	9	9	8

Figure 20 – Evaluation tables for producing the CSI and FBT scores of projects

The company already employed a system of tracking the direct cost of the project and evaluating its financial success at completion – however, this assessment had an internal tactical focus – but lacked somewhat in giving strategic overview or being customer focused. The final “score” that was looked at after the project's completion was de facto its profit margin. The author supposes that a more customer-centric approach is needed to get a more useful evaluation. A hypothesis was made in regards to which main

factors contribute to the project's success or lack thereof. The author supposes that these include the following factors which could be rated on a scale of 0 to 10:

- Foresight – or quality how good was the original product that was shipped to the customer. If, after commissioning, the product fulfilled its purpose as the client would expect with only minor tuning required during this stage – the project receives a solid 10 out of 10 points. If, however there were notable fixes which involved redesign and significant adjustments – we will subtract 1 from this score for every problem eliminated during commissioning and noticeable to the customer.
- Budget – how frugal and efficient were we in regards to the interests of our company when executing a project. If the project's cost ends up on line with its initial planned cost – meaning the company achieves its planned profit margin for the project: we score the project a 5. If it is seen that we have executed the project near its financial break-even point or worse – we score the project a 0. On the other end of the spectrum it is possible to see projects that have produced a higher profit margin than expected – if the profit margin is twice of that which was planned – the project receives 10 points in this category
- Time – were we on time – this parameter is somewhat correlated to the project's foresight score but, in the author's opinion requires an independent assessment. For every unforeseen week that we went over the deadline negotiated with the client before and during the execution of the project we shall subtract 1 from the maximum of 10 points achievable if the project was handed over on schedule to receive the Time score for the project.

Budget is based on assessing direct costs and remains almost completely an internal factor, while Foresight and Time are reflect the amount of value delivered to the customer as well as giving form to the hidden overhead costs associated with a given project for Tech Group. This new system should produce a score of how well the company is doing in regards to its strategic goals of being a top quality production automation partner to its client's over the years to come.

To assess the difficulty of executing a given project – past projects were assessed in three categories, which are believed to reflect the projects' complexity for the design department. These factors would need to be orthogonal so as not to be redundant. In the

beginning the author had more factors in mind, but when looking at the correlation between them – has reduced the lot to just three factors, which at the time of writing seemed sufficiently independent of each other. These factors are contingent on parameters the ones which are visible at the beginning of any given project. Those which are not immediately apparent should be deduced during the kick-off meeting. These criteria are:

- Complexity – is a weighted sum of technical factors that have been empirically found to influence the success score of any given project.
- Size – the size of the project as reflected by its budget based on the commercial offer that the client accepted.
- Insourcing – the amount of budget foreseen for equipment which is not outsourced, so for example if we purchase conveyors, robots or programming services from outside the company – we exclude that sum from the total sum of the project and are left with the amount of resources dedicated to equipment which is manufactured based on in-house design.

These factors were then weighted against project number 14_018 – a recent customer project that went terribly wrong. This project was notable in size, completely insourced and had a great deal of apparent (known unknown) and hidden complexity of the unknown unknown kind. Although financially this was not a complete failure – it took the company nearly an extra year of cooperation with the client at his premises to get the machines working right and signing the hand-over agreement. This project is fresh on everyone's minds and serves as a good yard-stick to measure other projects against – as such the final evaluation in the CSI system is attained when we divide the values for a given project with corresponding values of our benchmark project to receive corresponding coefficients.

All of the calculations are done in a spreadsheet prepared by the author, where at the kick-off meeting the team need only input the necessary parameters. The Size and Insourcing coefficients are rather straightforward, while the Complexity coefficient is in turn made up of subcategories which would with high likelihood reflect the amount of problems that would need to be solved during design. Initially the author supposed that this would be a score given by the project participants at its onset. But it was apparent that this would be (a) subjective (b) we could not gather data on past projects without the intervention of hindsight in everyone's minds as to how that project actually played out. So the author has chosen to create a score based on factors which were as objective as possible

and are visible at the start of any given project. At first there were four total factors proposed for gauging the complexity of a project. Which, in the final revision, to the author's surprise, were reduced to just two objective factors which are easy to assess and which would produce a high negative correlation with the project's FBT success score. The factors considered were as follows:

1. Amount of Sensors and inputs – factor 0,1 – any sensors or human inputs i.e. switches that influence the flow of the process count towards this score. For example if we have two inductive proximity sensors and three manual switches by which the operator can change the way the process unfolds – we count a total of 13 items, which add a factor of 1,3 to the final complexity score.
2. **Amount of motors and actuators** – factor 1 – any rotary or linear actuators count towards this part of the score in a straightforward fashion as do more complex machines that we purchase in one piece – for example if we have three motor driven conveyors, five pneumatic cylinders and one multiaxial robot we add 9 points to the final complexity score.
3. **Unique products handled** – factor 10 – is the measure of configurations the final machines will need to have to handle the prescribed flexibility in regards to the customer's product range being handled. This is a non-linear factor, as the complexity of design rises significantly if there is a need to make a flexible machine with different operating configurations – but in the usual range of one to three distinct products the author would suggest scoring a project with a 0 if there is just one product being handled and two or three accordingly if more product configurations will be used.
4. New principles used – factor 10 – slightly subjective criteria which the project internal stakeholders vote on at the kick-off meeting. For example if we have a new type of conveyor belt being used with a product we are unfamiliar with or a new PLC system principle we add one to this score for every principle which we have not used within the company.

As noted only the points 2 and 3 from the list above made it into the final classification tables. In fact the omission of points 1 and 4 which were initially postulated has given us a slightly higher negative linear correlation coefficient than when using these factors. With the four of the above factors being plotted against the projects' FBT scores produced an R^2 value of -0,74; while using only the second and third factor produces the picture below with a statistically more significant R^2 value of -0,76.

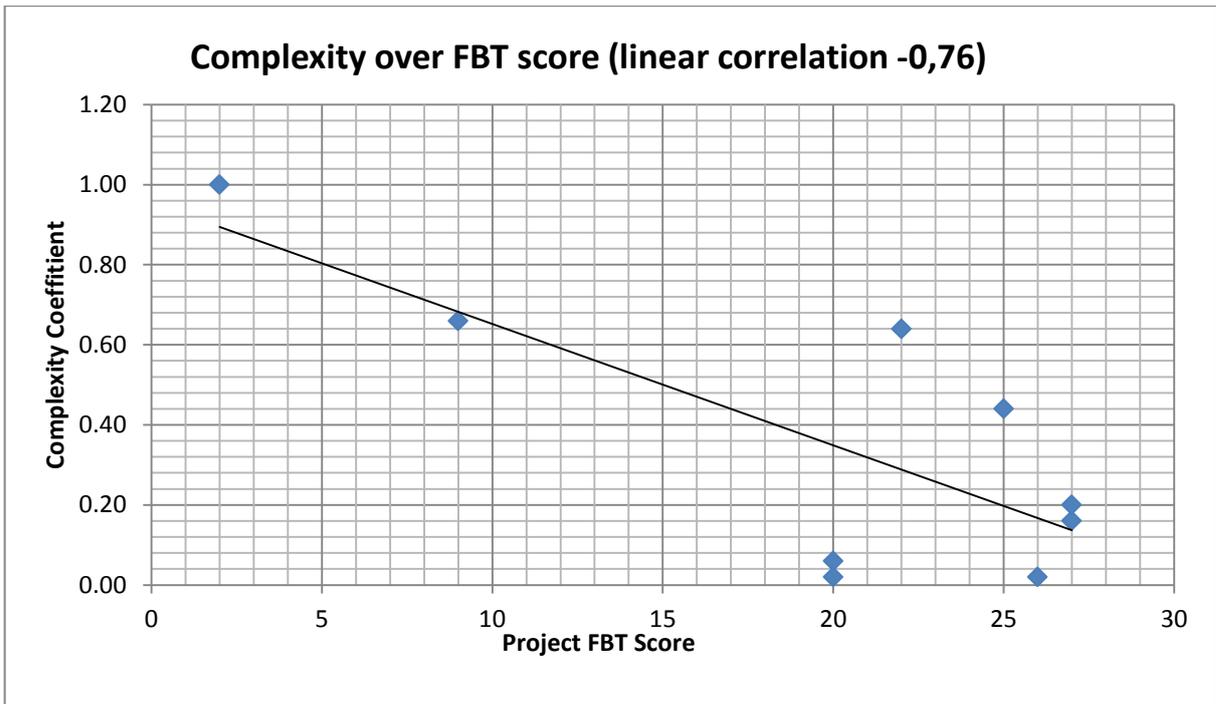


Figure 21 – Complexity coefficient over the success score of the project

To adjust the weights of the components of the complexity score to their now cited values – the author has worked backwards from the FBT to empirically achieve a high negative correlation coefficient between the final project score and its complexity factor. As can be seen from Figure 16 – Complexity over the success of the project – a negative correlation coefficient of -0,76 was achieved – which the author deems as sufficient in significance to keep the weights of the complexity components of the project at their final proposed values. Special care was taken to employ criteria that would make this part of the classification distinct from the Size score, since even smaller projects which are innovative to Tech Group need extensive testing and attention at the design stage even though this may not be immediately apparent through the workload planned for their execution.

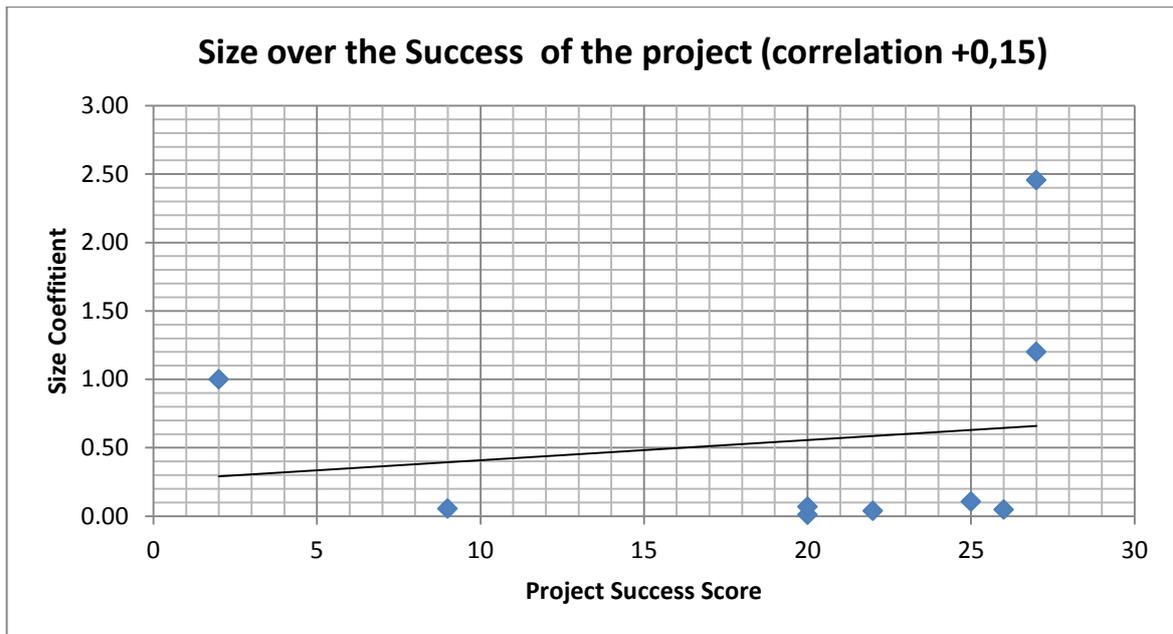


Figure 22 – Size coefficient over the success score of the project

As we can see from the figure above size is not a major historic component by which we can gauge a project's success – large projects can be executed well or small projects can have terrible outcomes. It is interesting to see, however, that some larger projects are executed so well that the theoretical correlation between size and success, although not statistically significant, has a positive value. What this shows, in the opinion of the author, is that the company has an inherent tendency to adjust for project size accordingly – taking more care and allotting more resources for larger projects. On the other hand this implies a slight tendency of the company to overlook the complexity of smaller ones. But in principle this chart shows the picture that should manifest in regards to new projects and the other CSI coefficients versus the FBT score, with, hopefully, significantly more clustering of the projects on the right hand side of the charts. Ideally the success of the project should be a stochastic value independent of any objective criteria apparent at the start of the project. After this we can try and postulate some new criteria which would show notable correlation with improving our project success scores – but for temporal reasons, this is outside of the scope of this thesis.

3.1.2. Paranoid project checklist

“Doubt is the father of invention” – is a phrase famously ascribed to a notable contributor to the scientific method – Galileo Galilei. In spirit with these words the author has developed a checklist to be used when developing and assessing the company’s experience in regards to the complexity of developing products that would help produce controlled physical processes that solve the problems of the customer. This checklist was developed with input from engineers and employees with significant experience at Tech Group who have helped outline the more problematic areas and frequently repeated mistakes that may come up during the testing and commissioning of a novel ETO project.

The paranoid project checklist (PPC)

Problems with customer's Tasks

- T 1 Unconfirmed layout for the project
- T 2 Unconfirmed quality goals of the project
- T 3 Unconfirmed control logic

Problems with Overall process

- O 1 We have never done this type of project before
- O 2 We haven't seen any analogues for the solution
- O 3 We aren't sure what the customer wants
- O 4 The proposed sequencing of the processes is wrong
- O 5 The quoted solution is not right for this purpose

Problems when handling Products

- P 1 The tolerances of the product being handled are inconsistent
- P 2 The effect of friction between the product and machinery is difficult to predict
- P 3 The product is too light/heavy/small/large/brittle
- P 4 Feeding into our system is not consistent in time and quality

Problems with sub-process A

- A 1 We have never implemented this process before
- A 2 The manufacturers of equipment have not approved its use for this purpose
- A 3 It cannot be done within the allotted tact time
- A 4 The output tolerance of the process is inconsistent
- A 5 The frame/motors/transmissions are too weak
- A 6 Conveyor transitions will cause problems

Figure 23 – The Paranoid Project Checklist Template

The list above features TOP priority doubts – which should be clarified as soon as possible so as to confidently move on with breaking the project down into solvable

deliverables. Practice has however shown that some of these problems may remain unsolved right up to the commissioning process – this is far from an ideal picture that has to be attained in tune with the „fixed scope“ PMBOK philosophy – but is an inescapable reality in a world where:

1. Process improvement and related product development are usually out of scope of the client’s core competence sphere.
2. The client’s core competence sphere and related nuances are new to Tech Group.
3. Extra complexity and risk is guaranteed if:
 - a. There is a new site being developed for the production line concurrently with the project.
 - b. The development of the product for which we are automating the process is not finalized by the client which leads to changing requirements for its automation process.

As such perfect process and product specifications are a rare sight as an input for an ETO design process – on the contrary they are usually a product of the product design process which should accommodate empirical approaches to fill the gaps in knowledge and understanding of the project stakeholders. However, the author hopes that by outlining and giving transparency to the problems which are usually encountered during the execution of ETO projects – the stakeholders will with higher probability be motivated to tackle them and avoid them or – if needed – to embrace the inherent uncertainty ahead and approach the more difficult parts of the project with due care.

This all gave the impetus to write the Paranoid Project Checklist (PPC) in the negative form so as to underline that there are sure to be problems ahead if the stakeholders do not acknowledge their presence accordingly from day one. When any of these points cease to apply to the project at hand – they are simply deleted from the checklist for a given project. Hopefully, as many as possible lines will be deleted on the first planning meeting for the project, and those which are not will be dealt with shortly. Some of these may however remain on the table up to the point of handing over the project to the customer, what is of importance – is that these stumbling stones are not swept under the rug at any point of the project, but acknowledged with all due respect.

3.1.3. Product backlog and burn down chart

So as to further improve the transparency of project progress the author sees it necessary to adopt a tool straight out of APM in the form of the product backlog and work burn down chart. The product backlog is a list of prioritized work break down structure. This structure should be kept rather rough so as not to encumber the team with planning overhead and also not box the team members into solving the tasks any given way right after the first planning meeting.

An example of these instruments can be seen in the chapter “A practical overview of an ETO project”. The tasks that are the result of the breakdown of the work are prioritized and given scores based on their difficulty starting from 1 and going up to 2, 3, 5, 8, 11... all the way up the Fibonacci sequence. This is done to highlight the increasing risks including unknown unknowns in the work that is judged to be increasingly more difficult than other tasks in the project. Every bit of work may be further subdivided into different completion stages. The author has found it helpful to divide tasks up into three readiness classes which can be shortly summarized as:

- Principle – score factor 1 – the design principle for the process or the machine has been locked by the team and its members can carry on executing further detailed modeling and component selection.
- Critical – score factor 3 – the basic design work on the component or task has been completed so that other people or departments can further use it to build upon and deliver value to the customer – during mechanical or electrical design this usually implies that the designers have compiled a BOM or an I/O list respectively which can be used by purchasing, programmers and other designers.
- Done – score factor 2 – this means that the task is done in all sense of the word – BOMs are available, all the documentation has been created and finalized such as assembly drawings and electrical diagrams.

The related score factors are then multiplied by the task score to get the weighted score of completing the portion of any given task. For example if a task has a general difficulty of 8 – locking in its design principle is worth 8 points to the team, creating a critical component list is worth 24 points and finalizing and tidying up the design is worth 16 points. All this information can later be used to track the progress of the work – when any

given part of the task is completed on a given date the total sum of work remaining decreases by the weighted score of that task component. If the task progress seems satisfactory in relation to the ideal burn down line – which is for simplicity taken as a straight line going from 100% on day 1 all the way down to 0% on the planned day of completion of the primary design stage of the project.

As such the aggregate score of work remaining should reflect a rough estimate of the complexity and uncertainty as well as the actual amount of work remaining. The weights for the components of the tasks as well as the task scoring system will be updated as more empirical information is gathered on the usefulness and accuracy of the current system.

A practical overview of the implementation of the system is shown in chapter 1.7 “A practical overview of an ETO project” in “Figure 27 – Burndown Chart for the primary design stage of the EPS project”. The spreadsheet drafted for this purpose will be used for further projects as well. The form of the burn down chart completely fulfills the requirements of increasing transparency of the state of the project while being unobtrusive in the way that managing it does not increase the overhead project cost in any notable manner.

This is by no means a tool to shorten the design process times, but merely to provide the team with adequate information on their progress and an incentive on producing deliverables which matter, If it is seen that we are falling behind the proposed schedule – the question is not – “how can we catch up and do everything on time”, but rather – “what impedes us and can we get rid of that impediment”. At times the answer to that latter question may lie outside of the current project – as in the real world the company handles many projects at a given time, all of which, depending on their priority, may need input from team members allocated to the project in question.

3.1.4. Company wiki

As was noted it is not easy to promote an effective learning process within an organization. At the same time it is of utmost importance if we consider the varying field of specializations engineers have to tread when dealing with varying projects. Tech Group already had a lessons learned policy of documenting mistakes and lessons relevant to a given project. Although this is indeed good exercise and a valid learning experience for the individual documenting the mistake it does little for the company or even a the design department as a whole as this useful knowledge would be stowed away in a project folder of which hundreds are added each year to the server folder tree of the company. It is good that if several years into the future a similar project comes to light and a designer or a project manager may remember that this or that looks familiar and that information should be gathered from folders A B and C – the three useful ones out of three hundred.

As such the author finds it of use to document this information in a more accessible way – a way which allows for simple searches and easy retrieval. There are many tools one can implement to this end, the author has decided to go with a rather basic and free (as in “free beer and free software” kind of way) package base on the Mediawiki engine, which was the original engine developed for the world’s most successful repository of general human knowledge – Wikipedia.

A test installation of the Mediawiki engine using XAMPP as the Apache platform was made on the author’s computer. Further a static local IP has been procured from the IT department, so that other users on the company’s local network could have a constant address to connect to if they wished to view or update certain information.

The author has tried to keep the wiki structure simple and provided some basic categories by which the articles are divided:

- Project: Documented Projects
- Design: Design and Engineering Handbook
- Component: conveyors, robots, sensors and notes on other notable items

Any given article can, however, belong to an unlimited number of categories which anyone can implement in the future; thus the knowledge base can later be viewed from many different angles. Furthermore as any set of hypertext documents this database is fully searchable which further increases its transparency and information availability. This all

provides a clear advantage over keeping the company's knowledge base stored as a set of documents in folders on a server. The author hopes, that this will provide a worthy incentive to the engineers to keep it duly updated with information that they have found interesting and this information in turn will aid them or future generations of engineers at the company to solve an increasing number of technical tasks with the benefit of well documented hindsight.

The screenshot shows the main page of the Tech Group wiki. On the left is a sidebar with a logo and navigation links. The main content area has a 'Page Discussion' tab and a 'Main Page' heading. Below this is a 'Contents' box with a list of five items. The 'Engineering handbook' section is expanded, showing links to 'Roller Conveyor with Belt Drive', 'Kuka robot - introduction and safety', and 'Motors and drives'. The 'Documented Projects' section lists five projects with their titles. The 'Documented Categories' section lists three categories. The 'Templates' section lists one template.

Page [Discussion](#)

Main Page

Contents [\[hide\]](#)

- [1 Engineering handbook](#)
- [2 Documented Projects](#)
- [3 Documented Categories](#)
- [4 Templates](#)
- [5 Getting started](#)

Engineering handbook [\[edit\]](#)

[Roller Conveyor with Belt Drive](#)

[Kuka robot - introduction and safety](#)

[Motors and drives](#)

Documented Projects [\[edit\]](#)

[\[redacted\]](#) - Candy packaging line

[\[redacted\]](#) - Cocoa bean unbagging

[\[redacted\]](#) - EPS stacking and packaging line

[\[redacted\]](#) - HS multiaxial router

[\[redacted\]](#) - Plywood Processing Robot Cell

Documented Categories [\[edit\]](#)

[Project: Documented Projects](#)

[Design: Design and Engineering Handbook](#)

[Component: conveyors, robots, sensors and notes on other notable items](#)

Templates [\[edit\]](#)

[Template:Component](#)

Figure 24 – Main page of the Tech Group wiki at the time of writing

3.2. Improved design process – events, flow and roles

The actual form of the design process will be determined by key events that take place during the project design stage. When and if these events actually happen is left for the stakeholders to decide in every specific case. The project stakeholders must be aware of all the possible events as well as the ability and the responsibility to invoke them.

Table 2 – Design process - events, agenda and stakeholders required

#	Event	Occurrence	Agenda	PM	Team	Client	Production
1.1	Site visit	immediately	Technical task walkthrough.	X	X	X	
			Measurements. Samples.				
1.2	Client Meeting	immediately	Technical task talkthrough. Refine scope.	X	X	X	
2	Planning	after scope is refined	CSI assessment.	X	X		
			Determine deliverables. Classify deliverables.				
2.1	Stand-up	preferably daily	What am I working on?	X	X		
			What impedes me?				
2.2	Design review	problem encountered	What has happened or changed?	X	X		
			Reassess design.				
2.3	Deliverable review	deliverable finished	Does the solution fulfill its purpose?	X	X		X
			Is it difficult or costly to produce?				
			Can we do better?				
3	Lessons learned meeting	project completed	FBT assessment.	X	X		X
			Determine important lessons.				
			Update wiki.				

The final four columns in the table above define the entities or their representatives which must be present at the various events of the project. The stages are split into 3 large categories with logically follow one another, the subcategories, however are unstructured and underlying events are invoked on an “as required” basis – the final decision on “what is required” is the project manager’s responsibility.

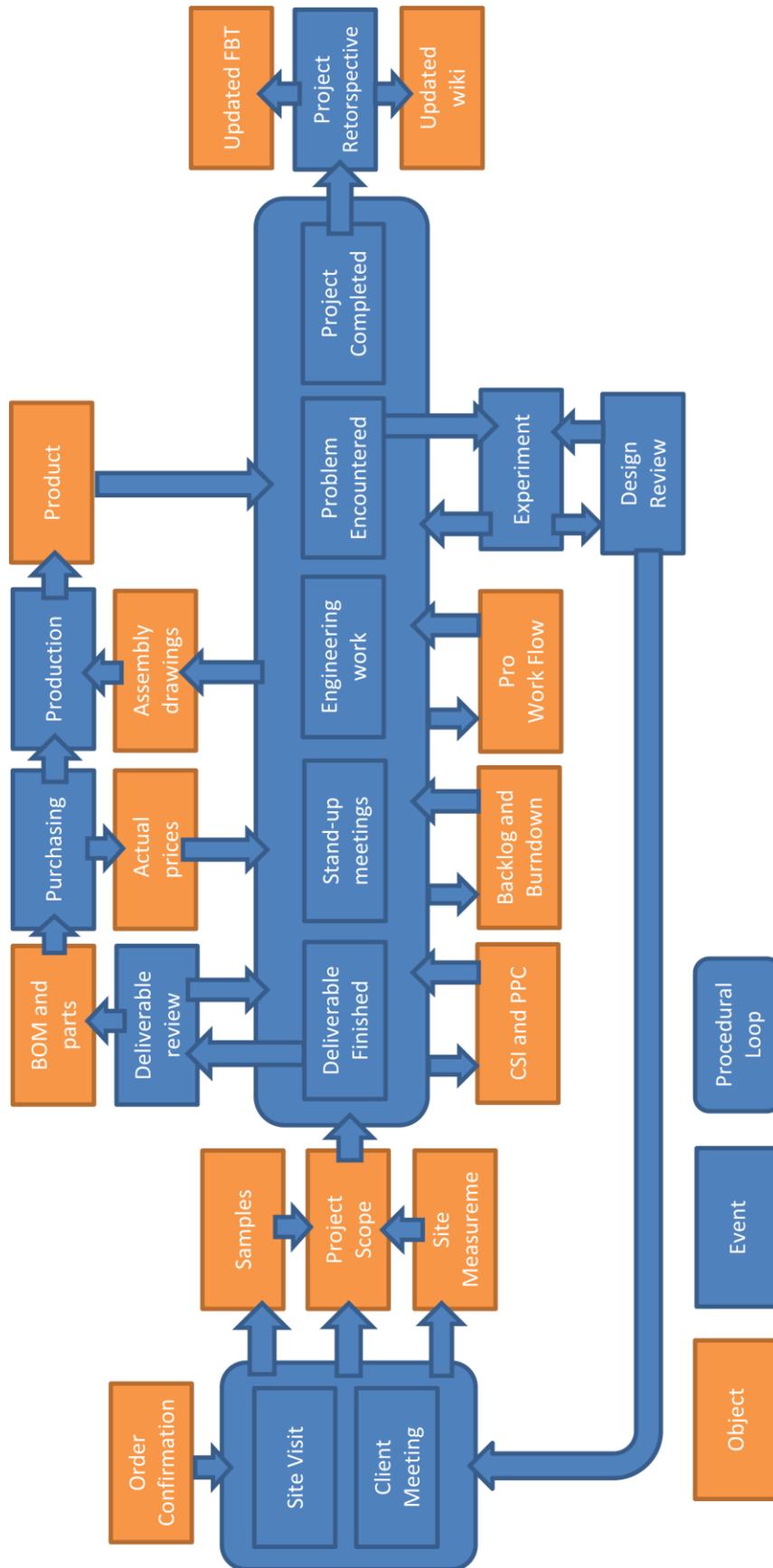


Figure 25 – Flow diagram of the refined design process

Every step in this diagram is an option that the project stakeholders may take, however it is an option that they must certainly consider. For example if we encounter a problem we should try and do an experiment – if we can't we should hold a design review meeting – if that is not needed we may simply go inquire the client and get some new input into our design process. Two large loops can be said to be running throughout the duration of the project: just as if we had two programmable logic controllers, one of which handles the interactions with the client and another one handles the events that arise within the company during the primary design stage. Projects should be executed with as little waste as possible – and what constitutes value in every given situation is up to the project stakeholders to decide on a case by case basis. The main purpose of the flowchart is to give guidance to the project stakeholders in regards to proven ways of handling events that arise during the project design stage and also the objects and artifacts that should be tracked and updated so as to try and improve the quality of the product of the project and retain new knowledge gained during its execution.

During design the project manager will encompass the roles of the product owner and the scrum master as discussed by the scrum methodology, the project manager thus:

- Understands and internalizes the requirements of the client in regards to the project being executed and is responsible for clearly expressing product backlog items.
- Optimizes the value of the work the team performs.
- Provides the team with the framework for executing the particular project and keeps it up to date with the temporal and qualitative requirements for the project.

The Development Team in its turn is a self-organizing entity interested in using its capabilities to solve the problems presented in the backlog in the best manner possible. In practice the team consists of engineers who are responsible for creating a process and its supporting documentation – drawings, diagrams, BOMs and texts – to help purchasing and production physically solve the task set by the customer. The team:

- Solves the technical task.
- Decides when their work is completed.
- Individual Development Team members may have specialized skills and areas of focus, but accountability belongs to the team as a whole.

3.3. A practical overview of an ETO project

The author had a possibility to make a test-run of the new design process on an interesting project during the period of writing this thesis. The project was an EOL solution for expanded polystyrene (EPS) producer. The product being handled was a range of EPS plates of varying thicknesses for the civil construction industry. The products exited the press mold vertically through a push cylinder system. They needed to be stacked and packaged into 500 or 600 mm high packs, which would later be stacked into a three meter “tower” which could be efficiently stored at the client’s warehouse. The client also had an existing wrapping machine that would need to be integrated into the new automatic process.

First of all a site visit was made to the customer by the project manager and an engineer, photos were taken, measurements were made and samples were acquired. The first project planning meeting was held. The complexity of the project based on the CSI evaluation table and adopted a proposed project resolution of two snapshots per week for tracking the progress of the project.

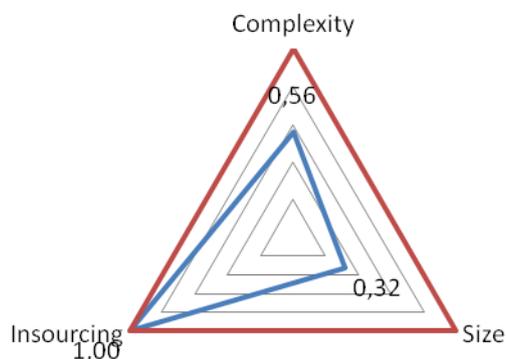


Figure 26 – EPS project's CSI score chart

In practice stand-up meetings were not held every day, with a median of about three short meetings per week, four one hour Design Reviews were held during the project where the team discussed various conceptual problems which required thorough discussion and collective input. Three practical experiments were carried out with the samples of the customer’s product and two intermittent Client Meetings were held to make sure that the project was on track with the customer’s expectations. One deliverable was ordered early to gain physical feedback from the subsequent prototype and help give insight into the actual budget constraints of the project. As a result three Deliverable Reviews took place – the final one as the BOMs and the part drawings for the whole project became available. At

the moment of writing the project has not come to an end, so no practical comments can be given on the Project Retrospective although some positive observations were made of the newly employed lessons learned policy supported by Mediawiki.

3.3.1. Work breakdown structure

The flow of the project was routinely interrupted by higher priority activity spilling over on the team from other due projects. The time of execution was in fact was historically proven to be the busiest time of the year for the company. The initial aggregate buffer for the project was thus quickly eaten up during the design stage, accordingly a few extra weeks of a safety margin were negotiated with the client, which in this case had no detrimental impact to customer relations, who prioritizes quality over time. Also of note was the drastic reassessment of scope that followed the development of key project processes. Below is the aggregate actual burn down chart of the mechanical design work executed for the project:

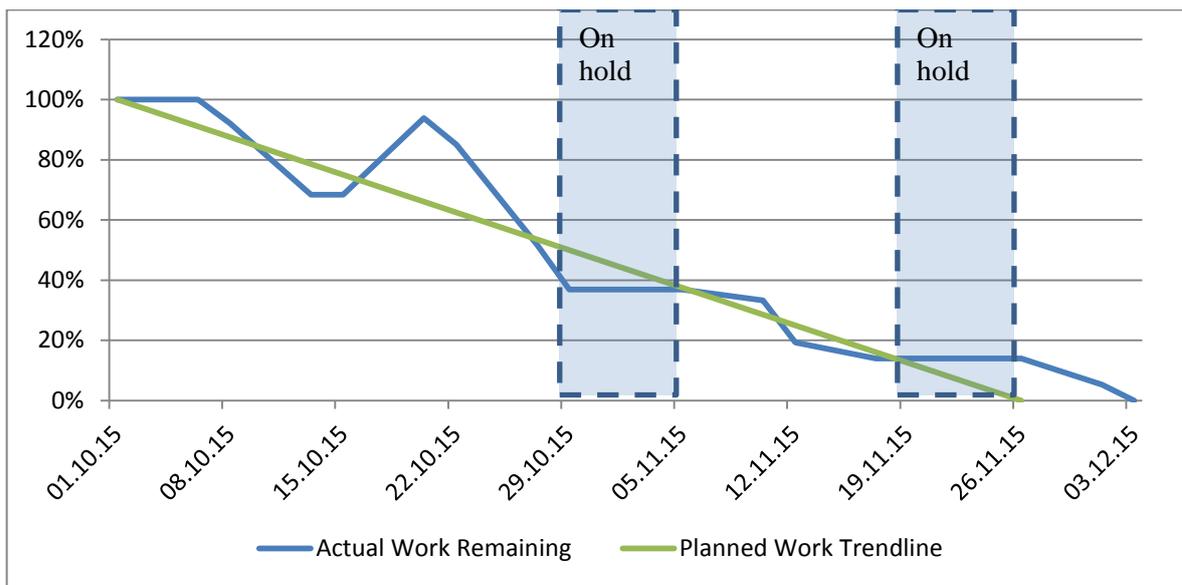


Figure 27 – Burndown Chart for the primary design stage of the EPS project

This chart is derived from the observations made during the course of design using the Breakdown and Burndown table. The planned work trend line could not be followed and the design process took a total of one week longer than was initially planned. However, this was mostly due to human resource constraints – with team members being needed in higher priority projects for a total of two weeks during the primary design stage of this project. The table forms the basis for this chart is presented on the next page of this document.

Table 3 – EPS project work breakdown and burndown table

				Date	01.10.15	06.10.15	08.10.15	13.10.15	15.10.15	20.10.15	22.10.15	27.10.15	29.10.15	03.11.15	05.11.15	10.11.15	12.11.15	17.11.15	19.11.15	24.11.15	26.11.15	01.12.15	03.12.15
Planned Work Trendline					100%	#N/A	0%																
Actual Work Remaining					100%	100%	92%	68%	68%	94%	85%	52%	37%	37%	37%	33%	19%	14%	14%	14%	14%	5%	0%
Diff.	Process	Stage	fact.	114	114	114	105	78	78	107	97	59	42	42	42	38	22	16	16	16	16	6	0
8	Rotation	principle	1	8	8	8	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0
8	Rotation	critical	3	24	24	24	24	0	0	24	24	0	0	0	0	0	0	0	0	0	0	0	0
8	Rotation	ready	2	16	16	16	16	16	16	16	16	16	16	16	16	16	0	0	0	0	0	0	0
1	Roller conv.	principle	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Roller conv.	critical	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	Roller conv.	ready	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Perp. Conv.	principle	1	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0
2	Perp. Conv.	critical	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0	0	0	0	0	0
2	Perp. Conv.	ready	2	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0
5	Stacker	principle	1	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0
5	Stacker	critical	3	15	15	15	15	15	15	15	15	15	0	0	0	0	0	0	0	0	0	0	0
5	Stacker	ready	2	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	0
3	Wrapper	principle	1	3	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Wrapper	critical	3	9	9	9	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0
3	Wrapper	ready	2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0

3.3.2. Iterative approach for producing quality and reducing risk

The curious occurrence on the 20th of October hints at the complete redesign of a key component of the project from the form that was offered to the client in the commercial offer. The need for this became apparent as the team gained more in-depth knowledge of the problem at hand and realized in concord with one of the postulates of the PPC that the proposed solution would not be either reliable nor the most economical for this purpose.

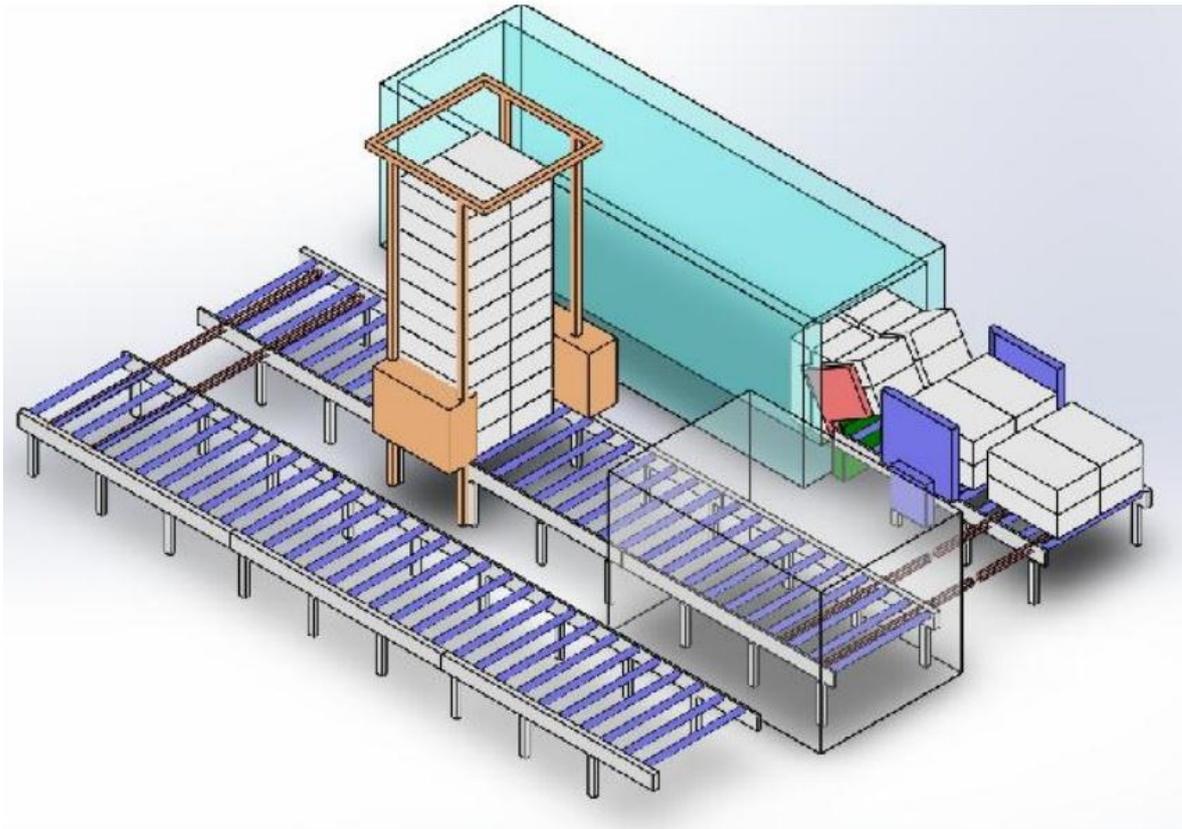


Figure 28 – Initial proposed layout of the EPS project in the price offer

The described issue concerned the part of the installation on the right-hand side of the above illustration – it was supposed that the existing mechanism would push the EPS plates onto a cart of sorts which would then rotate them into a horizontal position. As this solution was further developed it became clear that it would be too bulky and the rotational force required for carrying out this action would require a huge motor with an equally large chain transmission. As such this machine has changed its shape to that of a gantry manipulator with a vacuum gripper. This change was not a big surprise to the team as many alternatives were discussed in the prior meetings of how to handle this part of the process – one of them being the form adopted for the final solution.

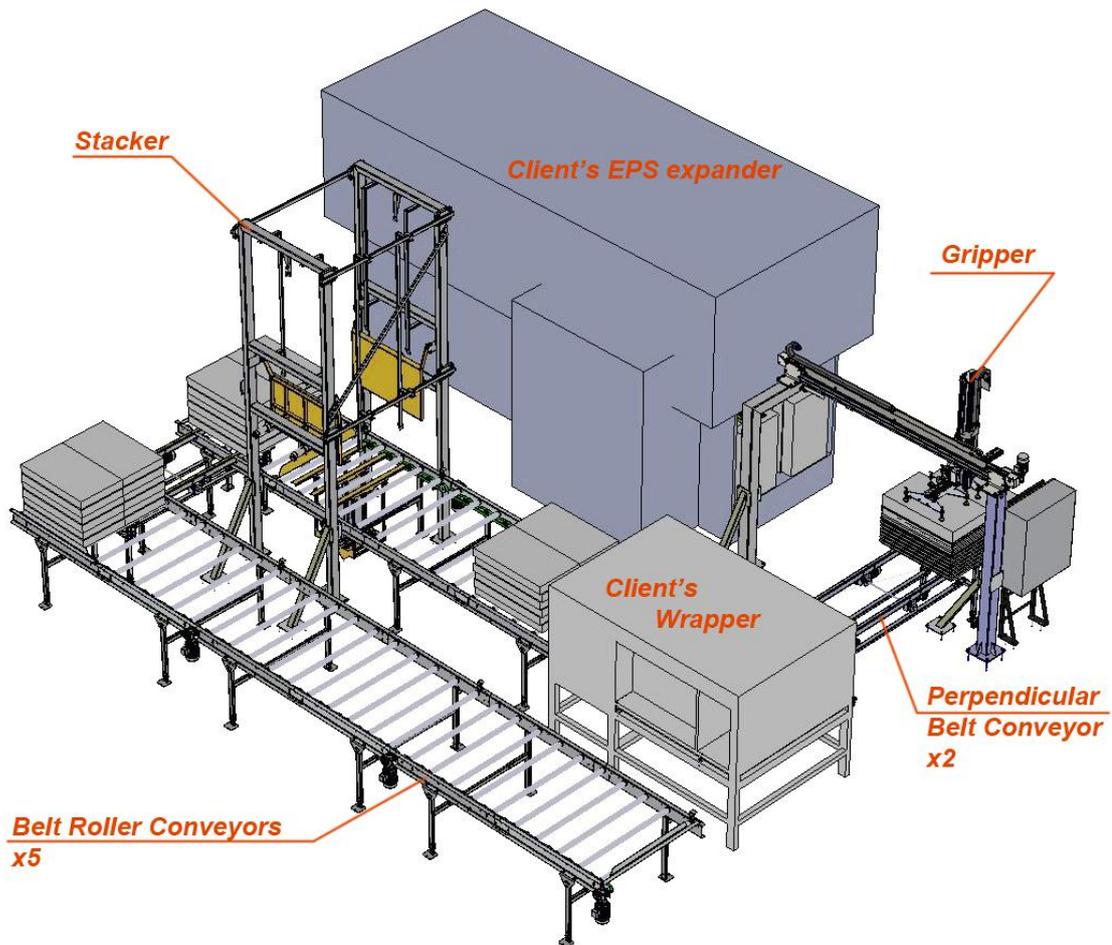


Figure 29 – Final version of the installation layout for the EPS project

The first priorities by the team were deemed to be the product Rotation and placing device due to its complexity and the roller conveyors due to them making up a large portion of the cost of the project. One can see these assessments and deduce the temporal priorities from Table 3 – EPS project work breakdown and burndown table. We also understood that the roller conveyors, of which there were at least 5 pieces planned for the project, could be finished quicker. These conveyors made up 28% of the initial budget so although simple, they were indeed a component that could influence the financial outcome of the project notably. Accordingly a prototype was made as an interim deliverable which gave feedback as to how to proceed.

The roller conveyors would be mechanically accumulating having a belt transmission from motor to the rollers, which would allow products to freely accumulate on the conveyors with no need for complex sensors or control logic. This same principle also gave softer starting and stopping motion for the load on the conveyors – since the load was made up of 3 meter towers of unbound EPS packages, it was an important feature, which

would be on the other hand costly to implement using chain drives, which would require frequency changers to make the resulting motion smoother. Tech Group, however, had no prior experience in building belt transmission roller conveyors, so they had to be designed from scratch. Due to the frequent meetings and dialogue between team members the resulting design proved to be simple yet robust. The total cost of the assembled 3 meter roller conveyor was only 60% of the budgeted cost. The cost became apparent due to the early delivery of the prototype which allowed to account for the both the direct and indirect costs of the assembled machine. As such the team could move ahead with delivering further components of the project with a clear understanding of a safety net or a leeway of sorts of 17% of the total budget saved on the roller conveyors.

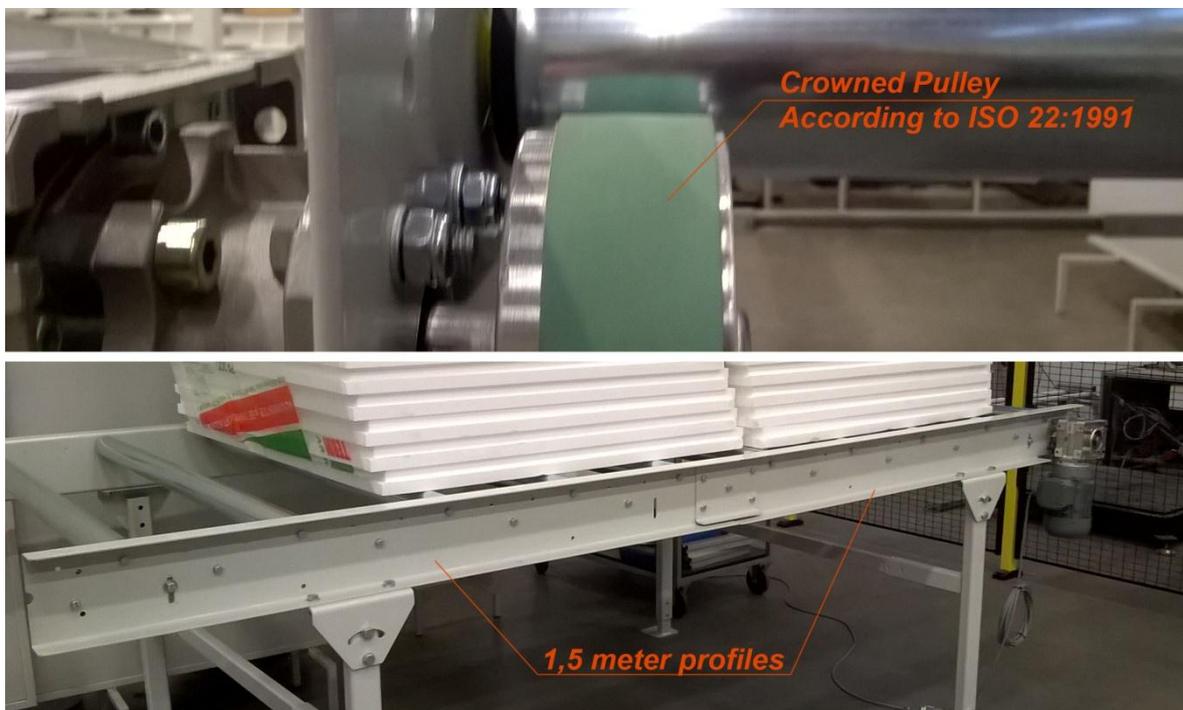


Figure 30 – EPS conveyor useful design features

Another useful feature that was implemented in the design of the conveyor due to research conducted by the team was the adoption of a crowned pulley on the driving shaft of the motor, this type of pulley, although not implemented by any large manufacturers whose designs the team studied during the design process – allows for easier assembly and more robust operation of the belt drive, due to the self-centering forces exerted on the pulley belt. Thanks to a Deliverable Review meeting and the input of purchasing we have also cut the main profiles of the 3 meter conveyor in half, so that the frame would be made up of 4 bent sheet-metal sections 1,5 meters in length each. This allowed for easier handling of the parts during transportation from the manufacturer to Tech Group and from

Tech Group to the paint shop and back, handling smaller parts during assembly showed to be easier as well.

Other deliverables for the project were handled in the same manner which allowed the team to make a cost-efficient and robust design overall. At the moment of writing the estimated cost for the machines in the project – based on the feedback from the purchasing department and the company’s standard values for overhead and workload cost estimation – looks good when compared to the budgeted cost which was allotted for the project – this all hints at the fact that the resulting project should be quite profitable for the company if no serious contingencies become apparent during commissioning.

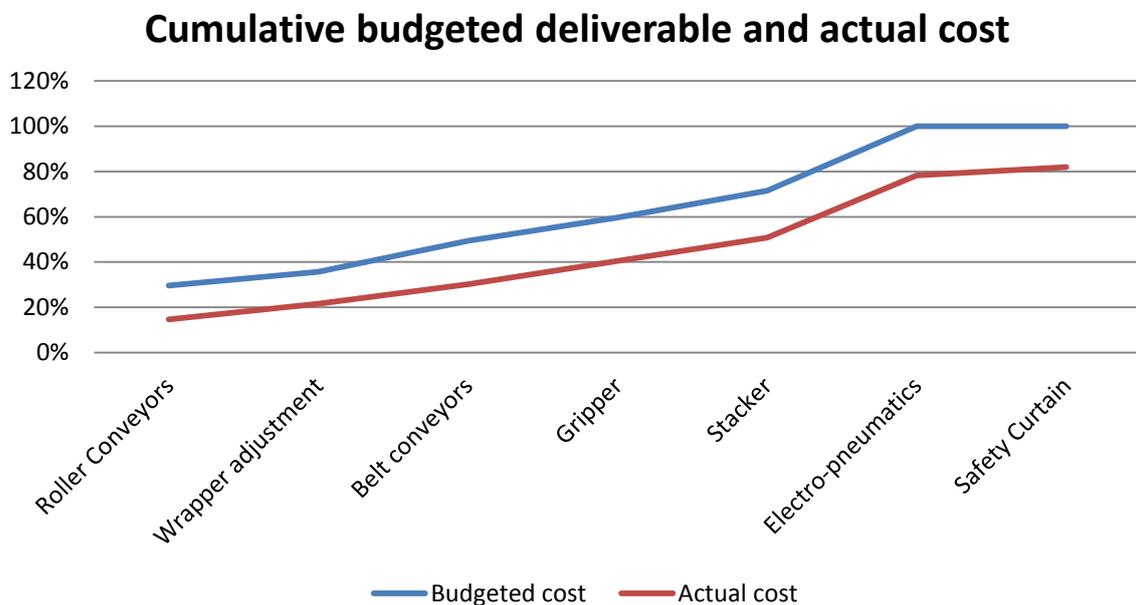


Figure 31 – Cumulative budgeted deliverable and actual cost

To shield the project from contingencies several experiments have been carried out with the customer’s product to make sure that the plan of action chosen for the technical solution would be suitable for the situation at hand. The experiments were based on questions that have arisen during design and – if unaddressed – could have led to a few unwelcome surprises down the road.

The first of these was the batch turning principle of stacks of EPS from the vertical into the horizontal position. This was in accordance with the first solution that was proposed in the accepted price offer. Troubling issues here had to do with several variations of thickness of the product and a simple and robust way to deal with the

resulting difference of measures when the plates exited the customer's expanding machine. Firstly some tests and measures were carried out at the customer's premises and lately in Tech Group with the sample products acquired for the design process.

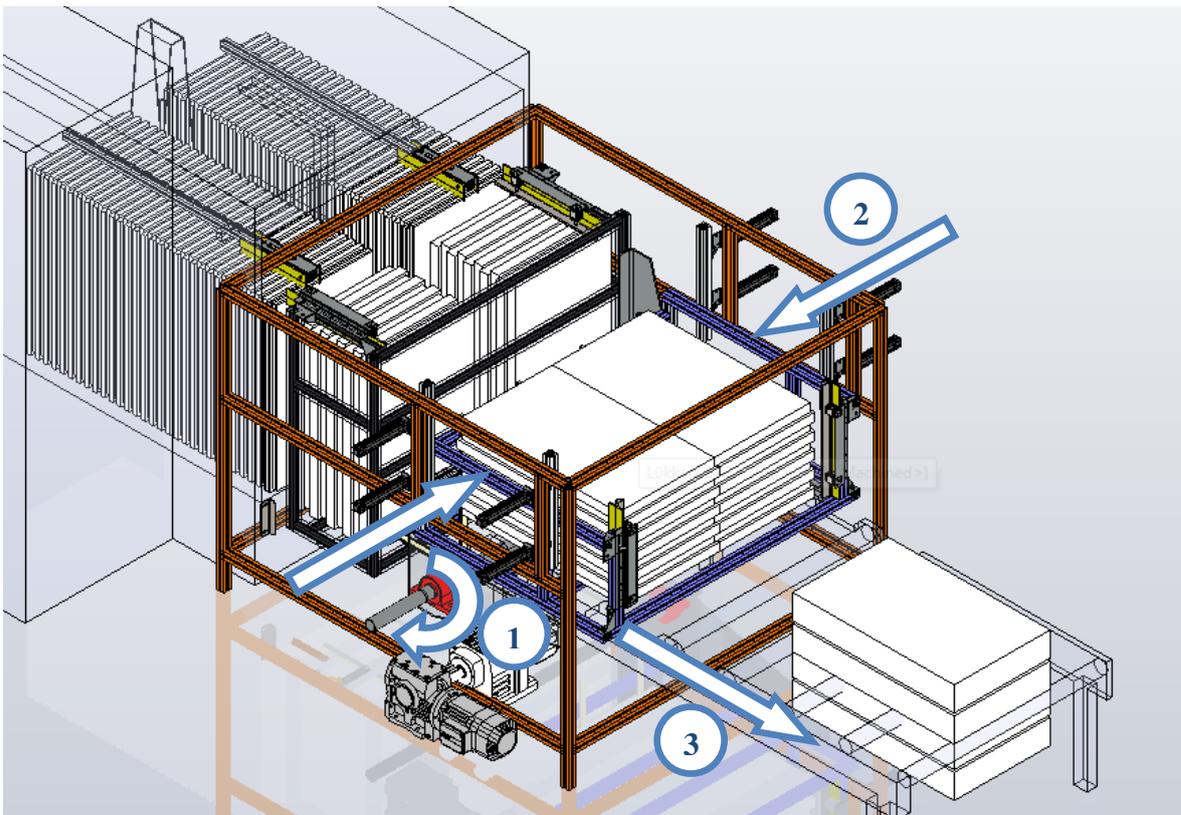


Figure 32 – EPS Rotation and Positioning device - first iteration

The team has spent a considerable amount of time developing the solution shown in Figure 32 – EPS Rotation and Positioning device - first iteration, however, many issues

were raised during dialogue at meetings regarding the possible problems with this solution that was within the initial scope of the project. When the weight of the frame for the rotation of the EPS plates could be exactly calculated in CAD and the resulting momentum required for carrying out the operation estimated – it became apparent that the relevant actuating motor would have to be huge with an equally unwieldy chain transmission to forward these forces into effective motion. This coupled with other concerns regarding the difficulty of making the process work with stability – led the team to a decision to scrap the concept and go with something different. An option was chosen from the possibilities discussed earlier – it was a pneumatic manipulator, which was not considered as a default solution due to the case of manipulators usually needing complex and costly control elements, such as servomotors or encoders and frequency changers and so on. However, the team now reassessed this solution and came to the conclusion that for this project the manipulator concept can be executed much cheaper than normally using pneumatic elements and some cunning sensor placement. The resulting machine with its most prominent cost-saving features is presented below:

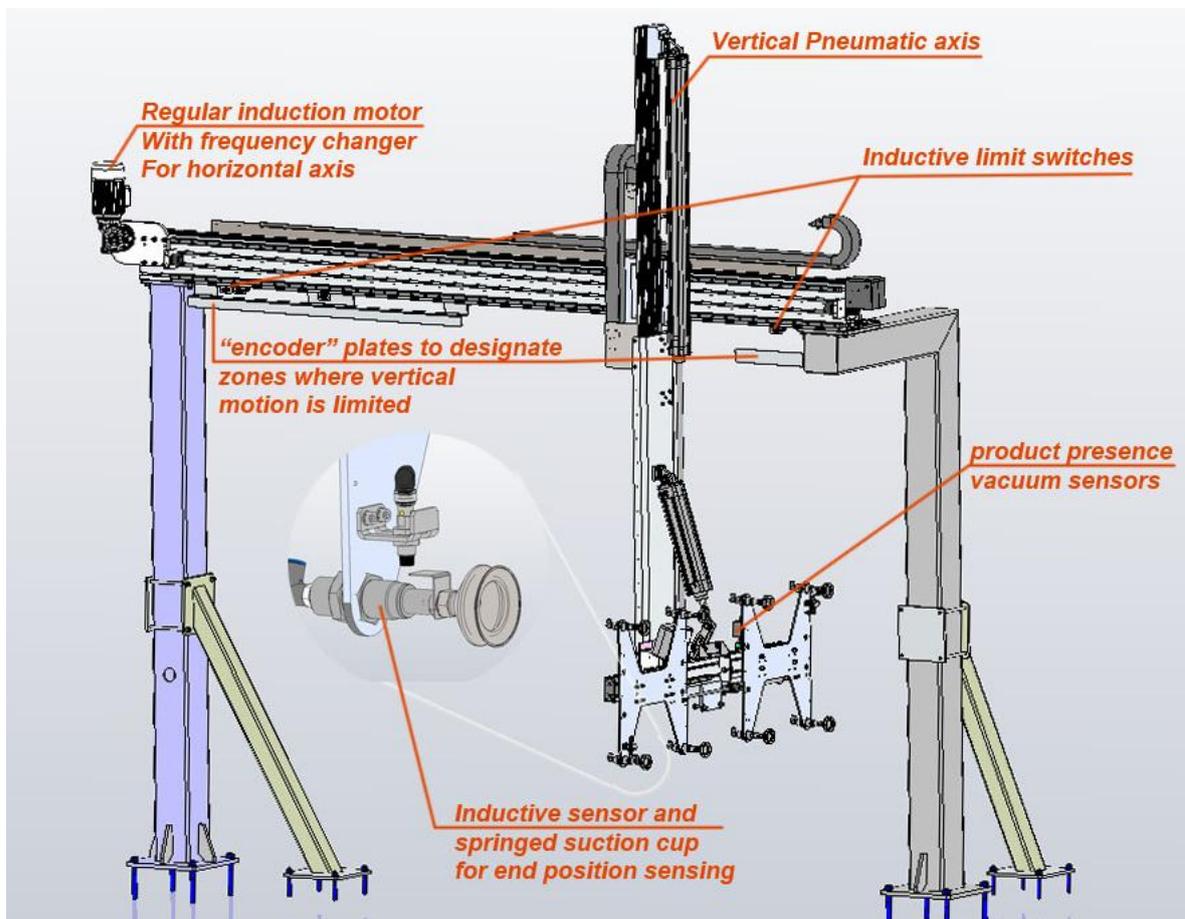


Figure 33 – EPS Rotation and Positioning device - second and final iteration

The final solution for the Rotation and Positioning device is made with the consideration of long cycle times of new EPS plates coming out of the expander. Considering this we can handle these plates one by one – thus reducing the weight of the material being handled in a single operation. The whole construction of the machine become lighter and generally nicer. Some key cost-saving features were developed (from the standpoint of being new for Tech Group) specifically for this project such as the use of inductive sensors in tandem with springed suction cups which allowed us to understand whether we have reached our end goal of taking or stacking the EPS plate rather cheaply. Further there was the problem of not allowing the manipulator arm to move up near the EPS machine or down too much near the conveyor where the EPS would be stacked so as not to damage any machines – this was solved again efficiently through the use of induction sensors and well placed plates. The obvious alternative (offered by engineers and programmers, at first glance) being an absolute encoder motor that was six times as expensive as a regular induction motor. Several other experiments were carried out before going ahead with design:

1. The suction principle was tested on the actual customer's product – which has led us to adjust the vacuum generators to a slightly higher rating due to the surface quality of the product.
2. The surface strength of the EPS plates was tested with varying loads and support constructions to determine whether the principles employed would damage the customer's product in a noticeable way – through this the forces and the required support surface areas were deduced for the process.



Figure 34 – One of the surface strength tests of the EPS plates: with loading in excess of 160 kg on rollers of 30 mm in diameter spaced at 300 mm

3.3.3. Economic Analysis and Lessons Learned

Based on the data from purchasing and manufacturing this particular project is scheduled to be 20% under budget in regards to machine cost. Although the primary design process took several calendar weeks longer than expected – this was entirely due to other higher priority work getting in the way of the team, with the actual time spent on mechanical and electrical design being 341 man-hours which means that only about 80% of the budgeted design time of 452 hours was used up. Several tests were made that helped reduce the risks related with designing the process. As practice shows there may be some contingencies that will use up some of the above profit gains during factory testing and commissioning but their size should not be too significant.

As one can see from the description of the design process in chapter 3 of this thesis – a waterfall type model for it, if created at the onset of the project, would lack relevance to the real way the design process was handled. Many feedback loops were used in the process to adjust the scope and the input parameters of the task based on empirical observations and calculations based on data that became ever more available with every day spent on the project. As such the iterative design process approach discussed in this thesis seems a more suitable and, what is most important, a useful model to develop further projects. Some Tech Group Wiki articles have also been added to the company’s knowledge base during the design stage of this project:

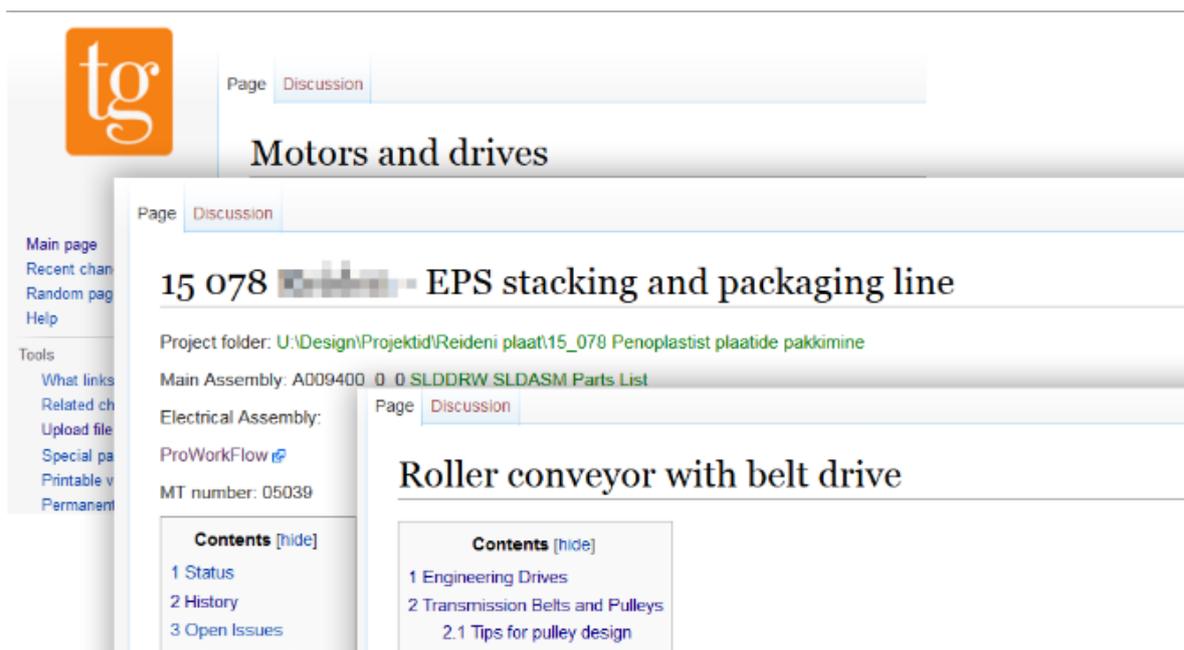


Figure 35 – EPS project resulting Tech Group Wiki articles

Conclusion

Actions were taken to create a set of tools and methods to promote a product design process that would allow Tech Group to continue delivering a large range of custom products in due time while reducing the risk of failed designs. The tools and methods created do not increase the overhead costs of the project while increasing transparency and promoting cooperation – just as planned. Whether the designs the refined process will produce will be consistently of higher quality than their predecessors will become apparent during further iterations of executing new projects. The first impression of the author based on the test project described in the thesis is that the improved design process is suitable for the tactical and strategic needs of Tech Group. The new product design process differs from the old one in the following notable ways:

Table 4 – Comparison of existing and newly adopted product design processes

Parameter	Status Quo Ante	Improved Design Process
Project Scope	Explicitly considered to be fixed	Explicitly acknowledged as floating
Unknown unknowns or hidden risks	Explicitly considered avoidable	Explicitly considered unavoidable – PPC
Project complexity assessment	Implicit – on the basis of the commercial offer	Explicit in view of historical data – the CSI table
Default deliverable of the design process	Completed project design with complete BOM, parts and assembly drawings	As required. Default sequence, in order of priority, being: <ol style="list-style-type: none"> 1. Standard components 2. Part drawings 3. Assembly drawings
Progress tracking	Implicit – opaque	Explicit – using the “Burn down chart”
Peer-review focus	Low	High
De facto responsibility for product quality	Team member as per his part of the project	Team as a whole
Meetings	Weekly 1 hour meetings	Daily stand-up meetings and longer ones only when required by project stakeholders
Responsible for judging a deliverable “done”	Project Manager	Team
Project results evaluation	Financial – own company focused	2/3 Customer focused – “Foresight, Budget, Time” evaluation table
Lessons learned	Confined to project folder	Cross-project body of knowledge in wiki form

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Kokkuvõte

Selles diplomitöös kirjeldab autor tootearenduse protsessi parendamist ühes keskmise suurusega tootmisettevõttes, kus ta töötab projektijuhina. Täiustamiseks on kasutatud meetodeid ja instrumente, mis kuuluvad paindlik projektijuhtimise (PPJ - ingl. Agile Project Management ehk APM) meetodite hulka. Tootearenduse protsessi parendamise eesmärk on projektidega seotud riskide ja ebamäärasuste maandamine. Kui projekti riske käsitletakse valesti – võib tulemuseks osutuda ebakvaliteetne toode, hilinenud tarneaeg ja sellest tulenev firma mainele kahju. Samas jääb tootearenduse protsess paindlikuks (sobiv laia valiku toodete arendamiseks) ning väikese kõrvalkulude osakaaluga – tegevused on suunatud kliendile maksimaalse väärtuse pakkumiseks.

Tootearenduse protsessi parendamist on analüüsitud ettevõtte Tech Group AS näitel. Ühe neljandiku ettevõtte käibest moodustab hetkel tootearenduse protsessi põhjal valminud projektitoodang. Projektitoodang on mitmekesine – alates väikestest koostamis- ja katseseadmetest, mis mahuvad laua peale ning lõpetades liinidega, kus viietonnised konveierid ja 250 kg tõstejõuga mitmeteljelised robotid on ainult osa lahendusest. Kuigi hetkel on omatoodangu käibe osakaal väike, omab selle toodangu mahu kasvatamine firmale strateegilist tähtsust, mis võimaldaks muu seas märgatavalt kasvatada olulisi majanduslike näitajaid nagu nt käive- ja tulu töötaja kohta.

APM on termin, mille alla kuuluvad projektijuhtimise võtted, mis on arendatud ja mida kasutatakse eelkõige tarkvara arenduses. APM ajalugu algas 1980. aastatel Du Pondis ning selle põhimõtted olid paika pandud lühiteksti kujul 1994 aastal (1994 Beck, Kent et al - Agile Manifesto). APM hindab eelkõige:

- inimesi ja nendevahelist suhtlust rohkem kui protsesse ja arendusvahendeid;
- töötavat toodet rohkem kui kõikehõlmavat dokumentatsiooni;
- koostööd kliendiga rohkem kui läbirääkimisi lepingute üle;
- reageerimist muutunud oludele rohkem kui algse plaani järgimist.

APM tunnistab, et ka parempoolsetel teguritel on väärtus, kuid vasakpoolseid tegureid hinnatakse kõrgemalt. APM filosoofia põhjal on loodud ka konkreetseid juhtimismeetodeid, millest populaarseim on Scrum. Scrum eeldab iteratiivset projekti käsitlemist ja kliendiga sügavat koostööd, tunnistades fakti, et enamike projektide puhul on projekti esimene päev just see aeg – millal projektist on teada kõige vähem. APM ja Scrum põhimõtted langevad

kokku Tech Group projektipõhilise tootearenduse tegelikkusega – kus firma klientideks on erinevatest valdkondadest tootmisettevõtted – alustades kommi ja alkoholsete jookide tootmisest ning lõpetades autoelektronika ja ehitustoodete tootvate ettevõtetega. Igal kliendil on oma spetsiifika ning otsesed ja kaudsed nõuded projektitoodete kvaliteedile. Kaudsete nõuete väljaselgitamine ja kaasnevatest teadmustest tulenevate riskide maandamine on projektipõhilises tootearenduses üks teravamaid probleeme, mis vajab erilist käsitlemist. Autor on proovinud leida ja arendada meetmeid, ja instrumente, mis aitaksid inseneridel ja firmal vastavaid probleeme tuvastada ja kaasnevaid riske maandada. Autori arvates tagavad projektitoodangu kvaliteedi eelkõige aktiivne firmasisene ning -väline (kliendiga) koostöö ja protsessi toetavate instrumentide läbipaistvus.

Töös on uuritud ettevõttes rakendatud tootearenduse projektijuhtimise protsess ning tuvastatud selle nõrgad kohad vastavalt Project Management Institute poolt välja antud Project Management Book of Knowledge metoodikale. Nõrkadeks kohtadeks osutusid madal kvaliteedikesksus, vähesed riskide kontrollimeetmed ja protsessi toetavate instrumentide madal süstemaatiline kooskõlastus. Probleemi lahendusena on pakutud iteratiivne tootearenduse protsess, mille põhiliseks eesmärgiks on luua väärtust kliendile. Protsessi kvaliteedi toetamiseks olid arendatud järgmised instrumendid:

1. Projekti hindamistabelid – lubavad hinnata projektide eeldatava raskustaseme ja tulemusi võrreldes varem teostatud projektidega:
 - a. Projekti keerukuse hindamistabel – kriteeriumiteks on suurus, allhange osakaal ning tehnilise raskusastme koefitsient, mille parameetrid ja kaalud on leitud teostatud projektide kvaliteedi ja algandmete korrelatsiooni analüüsi käigus.
 - b. Teostatud projektide hindamistabel – hindamiskriteeriumiteks on kvaliteet, tarneaeg ja eelarve – 2/3 projekti koguhinnangust moodustavad seega kliendile tähtsad parameetrid.
2. Korduma kippuvate vigade kontrollleht – mis aitab silmas pidada projektiga seotud riske ning põhineb autori kogemustel ja dialoogil tootearenduse osakonna liikmetega.
3. Projekti tööjaotuse tabel ja teostamise graafik – instrument mis aitab tööde jaotamise käigus meeskonnaliikmetel hinnata tööde raskusastet ja lisab tootearendus protsessile läbipaistvuse.
4. Tech Group Wiki – Mediawiki baasil projektide käigus saadud kogemuste ja tarkuste kogum, mida on mugav ja praktiline kasutada uute projektide arendamisel.

Rakendatud meetodite ja kasutusele võetud instrumentide abil on Tech Group teostanud ka ühe keskmise raskustasemega ja suurusega projekti. Selle tootearendusprotsessi käigus oli välja selgitatud ja teostatud, kliendiga koostöös ja eksperimente läbi viides, kõige sobivam lahendus vahtpolüstüreen plaatide pakkimiseks. Projekti alguses tundsid kõik projektiga seotud Tech Group insenerid, et projekti eelarve oli liiga madal ja ajaraamid liiga kitsad antud ülesande lahendamiseks.

Töö oli jagatud projekti tööjaotuse tabeli alusel ja oli kohe välja selgitatud, et projekti üks lihtsamatest komponentidest on samas ka üks tähtsamaid. Selleks oli rihmülekanega rullkonveier, mida oli projekti tarbeks vaja toota viis tükki ja mis moodustasid kokku 28% projekti eeldatud eelarvest. Selle komponendi oli võimalik kiiresti projekteerida ja prototüüpi toota – nii oli ka tehtud. Projekti algusest kahe nädala pärast, konveieri komponentide sisse ostmisel, selgus, et selle omahind hakkab moodustama ainult 60% konveierile eelarvestatud kuludest. See aitas projektiga edasi liikuda teades, et 17% kogu projekti eelarvest on varuna käes. Neli nädalat peale projekti algust oli näha, et prototüüp töötab hästi ja teda oli lihtne koostada. Arendustöö käigus viidi läbi vähemalt kolm korda nädalas lühidat (kuni pool tundi) koosolekud, mille käigus räägiti tehtud tööst ja ees seisvatest probleemidest. Ühel sellisel koosolekul selgus, et kolm nädalat arendatud pööramis- ja positsioneerimisseade ei oleks piisavalt töökindel ega majanduslikult otstarbekas sellel kujul millel ta oli kliendile algselt pakutud. Sellest printsiibist loobuti ning alustati kohe töö alternatiivlahenduse kallal – milleks oli iminappadega manipulaator. Manipulaatori arutati perioodiliselt koosolekutel ka varem, aga ainult läbiviidud arendustöö käigus selgus, et see on otstarbekaim lahendus. Tootmisest ja ostuosakonnast saadud andmed näitavad, et projekti lõpuks moodustavad tema reaalsed kulud tõenäoliselt 80% eelarvestatud kuludest ning inseneride poolt projektile kulutatud töötundide summa on eelarves plaanitust 20% madalam. Projekti käigus oli Tech Group Wiki'sse lisatud ka mõningaid huvitavaid artikleid, mis saavad olla abiks ja toetuseks inseneridele tulevikus.

Et olla kindel uue tootearenduse protsessi mõju määras projektide tulemustele on ilmselgelt vaja koguda andmeid suuremast arvust projektidest. Veel üks keskmise suurusega projekt on juba töös. Antud Diplomitöö käigus läbi viidud piloot-projekt ja autori kogemus pooldavad hetkel aga seisukoha, et APM põhimõtetel teostatud tootearenduse protsess on Tech Group jaoks sobilik ning majanduslikult otstarbekas nii lühi perspektiivis – vähendades projekti otseseid kulusid – kui ka pikemas – kuna kliendi ootustele vastav toode on tööstuses tegutsevale firma mainele põhi mõjufaktor.