

Researching the application of Pugh Matrix in the sub-sea equipment industry

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Abstract

We teach master students in Systems Engineering many methods and techniques that practitioners see as beneficial. However, we have little systematic evidence that support the claims that these methods and techniques are beneficial in practice.

This paper discusses the application of the Pugh matrix in six different cases in the domain of subsea equipment. The researchers have been students in the Master in Systems Engineering program in Kongsberg. These master students have been working in industry for three years. In the last half year of their study they do their master project. The master project is to apply a Systems Engineering method or technique in practice and to evaluate the application by writing an academic paper. Six out of 22 students, especially in the sub-sea equipment domain, chose the Pugh Matrix as technique for *Concept Selection*.

The application of Pugh matrix in these cases resulted in exploring more and farther reaching alternate design than in the normal practice. The exploration of these alternate designs and the explicit articulation of criteria for selection stimulate a learning process of the participating engineers. At the same time it is observed that day-to-day pressure and cultural aspects make older engineers hesitant in applying *Concept Selection* by Pugh Matrix.

Introduction

We teach *Concept Selection* techniques as part of the first course Fundamentals of Systems Engineering of the Master Systems Engineering (MSE) at Buskerud University College (BUC). *Concept Selection* takes place once the needs of the stakeholders are articulated and the requirements are defined. One of the techniques taught is Pugh matrices, where concepts are compared against a set of criteria by means of a matrix.

The subject *Concept Selection* is often chosen by master students from the sub sea industry. We had 20 students who did their master project in 2008 ad 2009. Nine of these students work in the sub sea domain, where five of these 9 students chose Pugh matrix as subject. From other domains, such as automotive, manufacturing, energy, defense, or maritime did no student chose Pugh matrix as subject.

The sub sea domain is project oriented. Project execution takes place under lots of time and cost pressure, with the consequence that often the first solution that is proposed is chosen. In product development it is recommended to explore multiple concepts to evolve to a proper

choice, see for instance set-based concurrent engineering in LEAN development (Kennedy 2008).

In practice, project leaders and engineers in the sub sea domain seem to jump to a solution based on a combination of gut feeling and cost feeling. The use of techniques such as Pugh matrices is perceived by sub sea projects as too time consuming and hence ignored. At the same time the engineers in the sub sea domain realize that skipping *Concept Selection* results in suboptimal systems, where quality suffers from time pressure.

Concept Selection

The course Fundamentals of Systems Engineering proposes a standard Systems Engineering process starting with stakeholders to find their needs. The project goal is formulated as a simple and clear Need statement. The needs are transformed into requirements setting the stage for the development and engineering process. Here the first step is *Concept Selection*, where multiple concepts have to be proposed. These concepts are compared to select the most suitable concept(s).

A commonly used technique is Pugh matrices, proposed by Stuart Pugh [Pugh 1981]. A Pugh matrix has the concepts as one axis and the criteria on the other axis. Every field of the matrix contains an assessment of that specific concept for that specific criterion. This basic concept can be extended by adding weights per criterion. See Figure 4 for an example of a Pugh matrix with weights and numbers. Figure 8 is an example of a simpler matrix without numbers, instead + (good), S (Same), and – (bad) are used.

FMC case studies

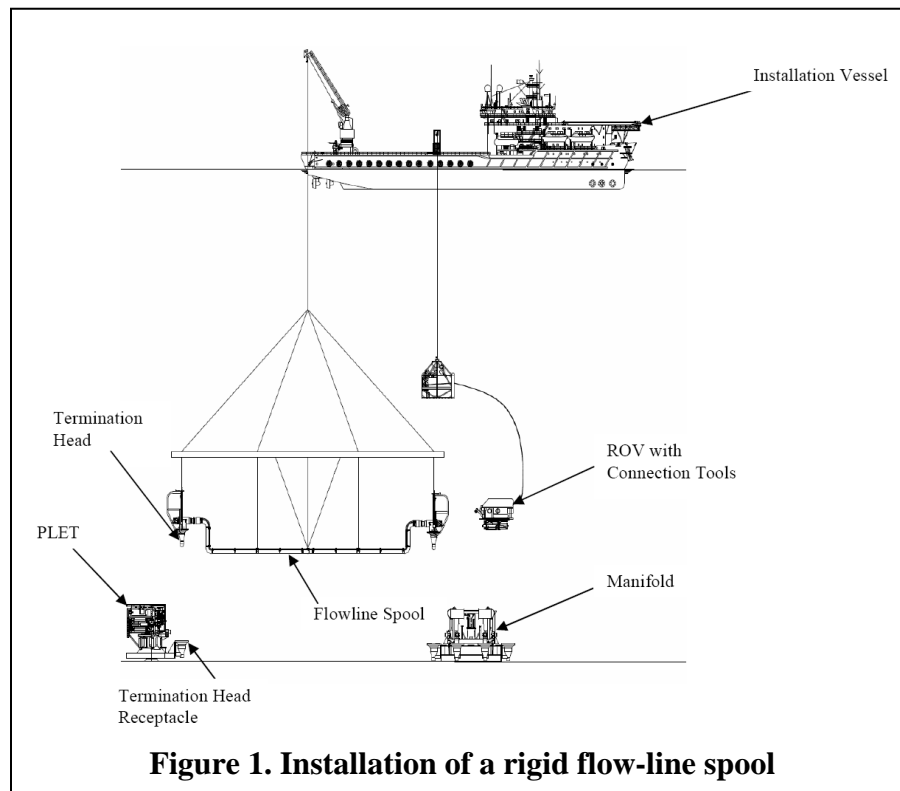
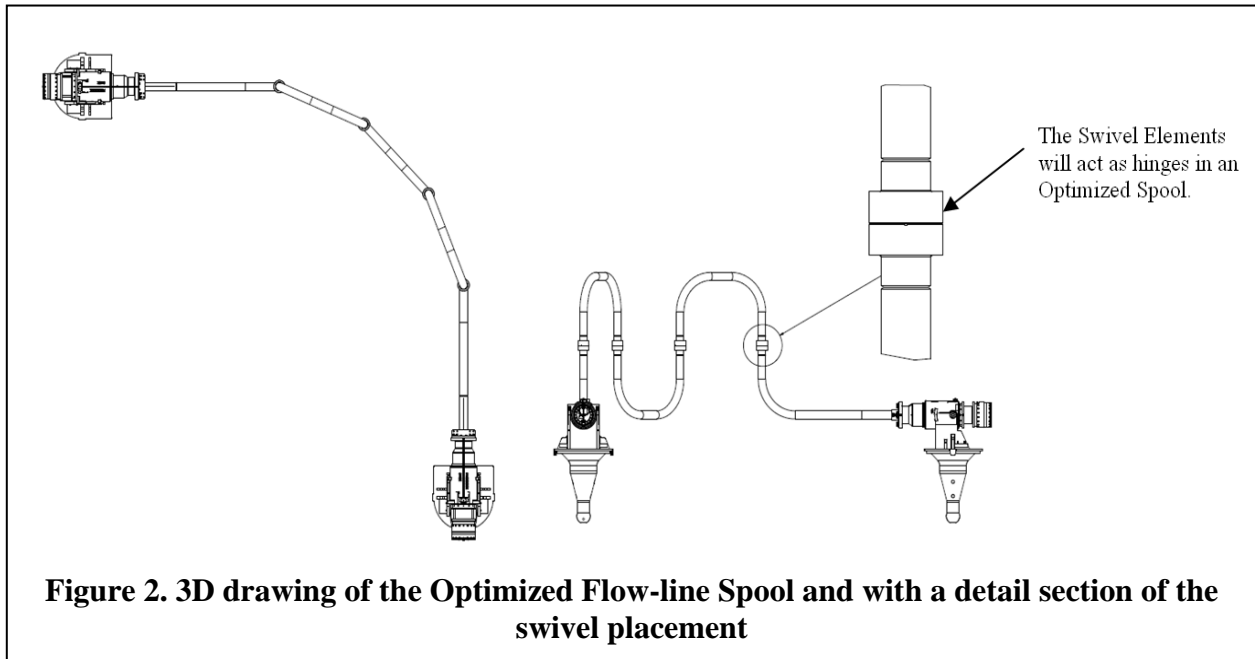


Figure 1. Installation of a rigid flow-line spool

The first two students that completed their MSE chose for their master project to apply Pugh matrices for *Concept Selection* in practice. Halvard Bjørnsen applied the technique on the selection of an optimized swivel for a flow-line [Bjørnsen 2009]. Dag Jostein Klever applied the technique on the selection of subsea connections [Klever 2009].

Figure 1 shows the context of the optimized swivel study. At the bottom of the sea in oil production fields a flow-

line connects the Pipe Line End Termination Structure (PLETS) with the manifold. The flow-line is a huge pipe for the transport of oil or gas that has to withstand large pressures and temperatures. At this moment every flow-line is custom designed and manufactured to fit the specific geography at the sea bottom.



The study looks into the possibility to make a more flexible flow-line by inserting a number of swivels. These swivels act as hinges, providing a degree of freedom of the angle in the flow-line, see Figure 2. If the flow-line has this additional flexibility, then the flow-line can be produced from more standard components. The use of standard components can lower cost, and also provides much more logistics flexibility.

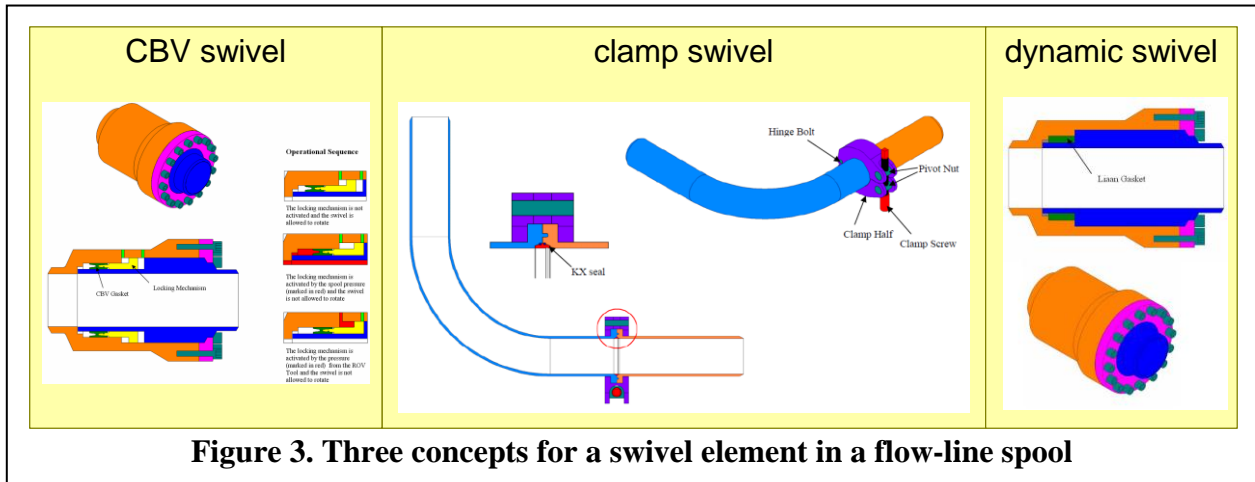


Figure 3. Three concepts for a swivel element in a flow-line spool

Bjørnsen made an inventory of available swivel technologies in FMC that can be used as starting point for the *Concept Selection*. He found three alternatives, visualized in Figure 3:

- a CBV swivel that can rotate during installation time, and locked afterwards
- a clamp swivel that also is locked after installation
- a dynamic swivel that by means of a patented casket can still rotate after installation

Evaluation Criteria	Weighed Points	Concept 1. CBV Swivel		Concept 2.Clamp & KX Swivel		Concept 3. Dynamic Swivel	
		Points, 1-5	Weighed Points	Points, 1-5	Weighed Points	Points, 1-5	Weighed Points
Maturity	10						
Development level		5	50	2	20	2	20
Cost	20						
Hardware Cost		4	80	2	40	5	100
Development Cost		5	100	2	40	2	40
Design Robustness	25						
Design Life							
Swivel Cycles		5	125	3	75	5	125
Pressure Cycles		5	125	4	100	3	75
Pressure Range							
Internal		4	100	4	100	4	100
External		2	50	5	125	2	50
Temperatur Range		4	100	4	100	4	100
Installation	20						
Initial Installation/retreivel		2	40	3	60	4	80
Connection/disconnection		2	40	4	80	5	100
Operation	25						
Swivel Resistance		1	25	4	100	5	125
Spool Length Short		1	25	4	100	5	125
Spool Length Long		3	75	5	125	5	125
Hub Loads		2	50	4	100	5	125
∑ Points	100		985		1165		1290

Figure 4. Pugh matrix for the concept selection of the swivel element.

Figure 4 shows the Pugh matrix comparing these three alternatives against maturity, cost, design robustness, installation and operation characteristics. This Pugh matrix uses weights per group of criteria. Design robustness and operational characteristics are the most important criteria with 25 points each. Individual criteria are scored on a scale from 1 to 5, where 1 is bad or poor, and 5 means very good, highly desirable.

The selection matrix shows that the dynamic swivel scores best in all aspects, except for pressure performance (less good in pressure cycles and external pressure), and except for development cost where the CBV swivel scores best.

Dag Jostein Klever worked on the *Concept Selection* for the connection between two sub-

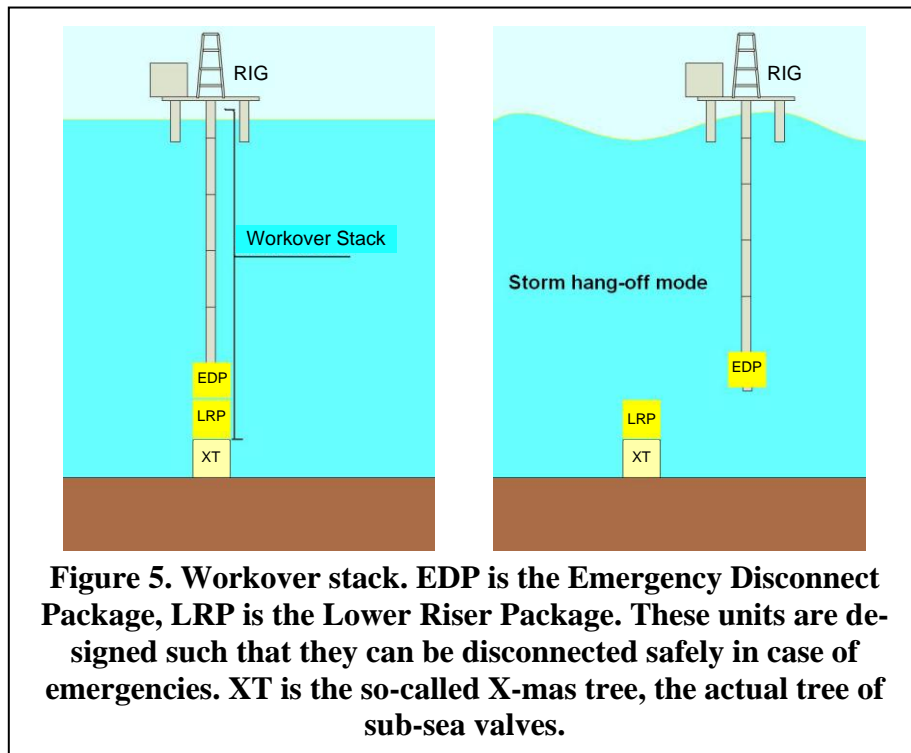


Figure 5. Workover stack. EDP is the Emergency Disconnect Package, LRP is the Lower Riser Package. These units are designed such that they can be disconnected safely in case of emergencies. XT is the so-called X-mas tree, the actual tree of sub-sea valves.

systems of the Workover Stack. The Workover Stack, see Figure 5, connects the Rig to the so-called X-mas tree. When the surface conditions at sea get bad, for example in case of storms, then the rig and the X-mas tree must be disconnected safely, without any spillage of oil or gas. The lower Riser Package (LRP) and the Emergency Disconnect Package (EDP) are designed to facilitate fast and safe disconnection.

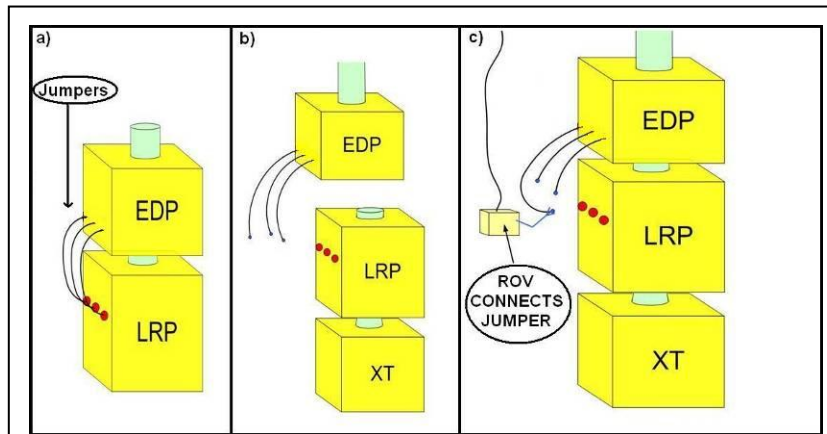


Figure 6. The current solution for electrical connections when disconnecting and reconnecting is by using cables with connectors at one side. A remotely operated vehicle restores the sub-sea connections.

LRP, see Figure 6. These connectors can easily disconnect when needed. The current solution has a few disadvantages:

- A Remote Operated Vehicle (ROV) is needed to make the connections.
- The connectors can be damaged which may require costly repairs of the EDP

The use of the ROV is costly. Repairing the EDP is even more costly, and the extended down-time of the field in case of damaged connections causes a big loss of income for the oil operator. Klever looked for connection concepts that overcome these disadvantages.

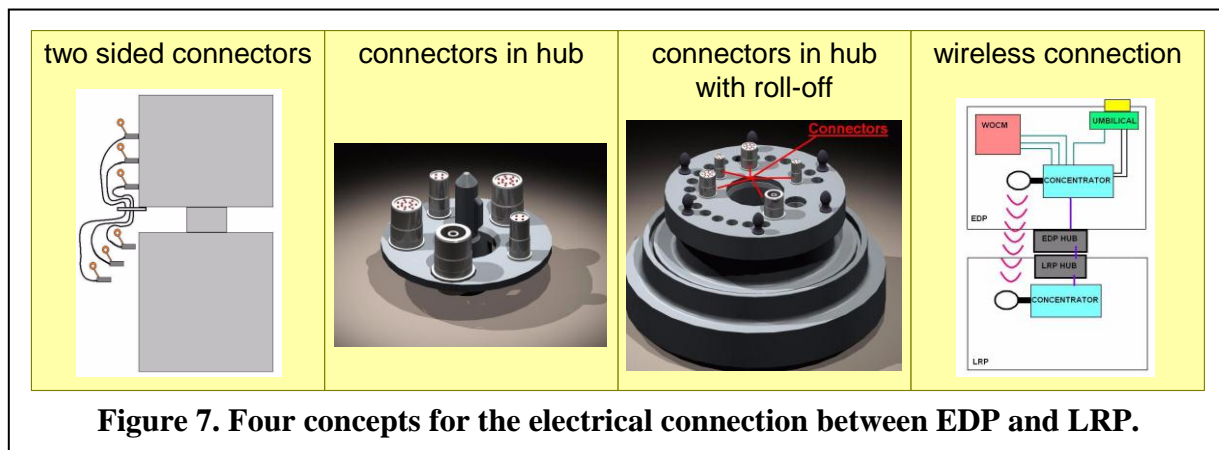


Figure 7. Four concepts for the electrical connection between EDP and LRP.

Figure 7 shows four concepts that have been discussed successively. The first concept replaces the fixed wires at EDP side by connectors. The idea is that when a connector is damaged that then only the wire with connectors has to be replaced. This relative small change does not change the need for a ROV for connection. The second concept moves the electrical connection into the hub. When the EDP is placed onto the LRP mechanical alignment guides the connections into proper placement. During the discussion of this concept a new requirement popped-up: the connection of EDP and LRP must be possible under significant angles, the so-called roll-off. The roll-off requirement triggered a new variant of an in hub connection, concept 3. Finally a

more revolutionary concept was added: a wireless connection where all electrical interface are multiplexed over one connection.

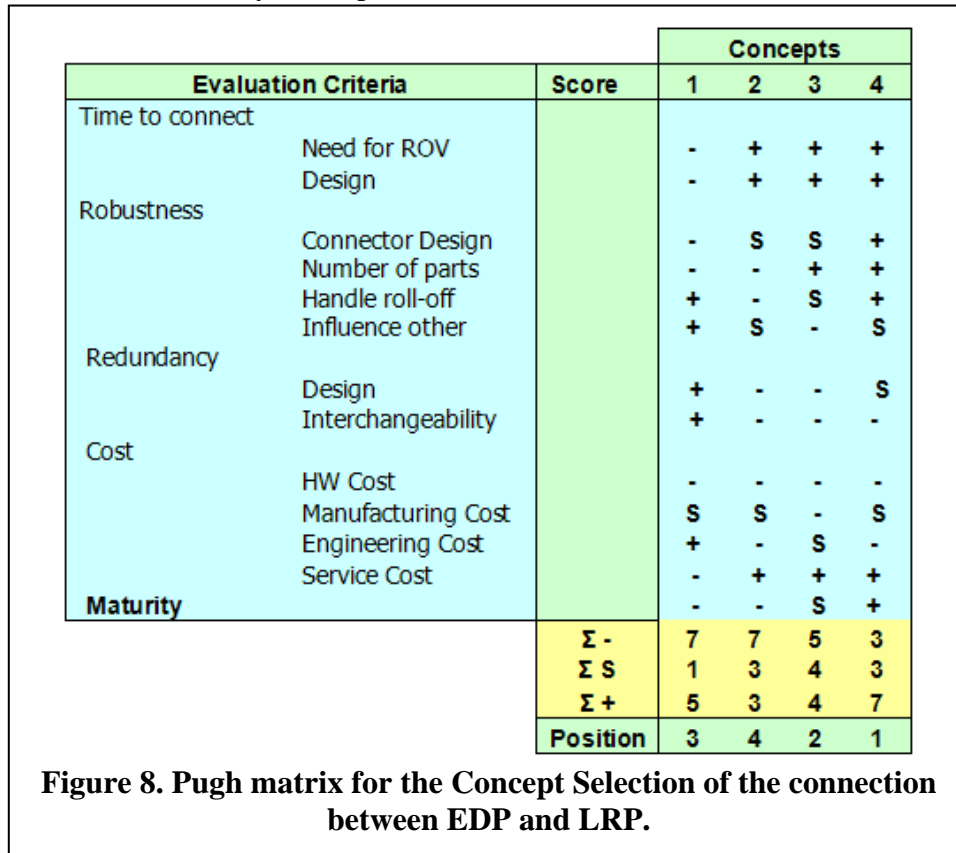
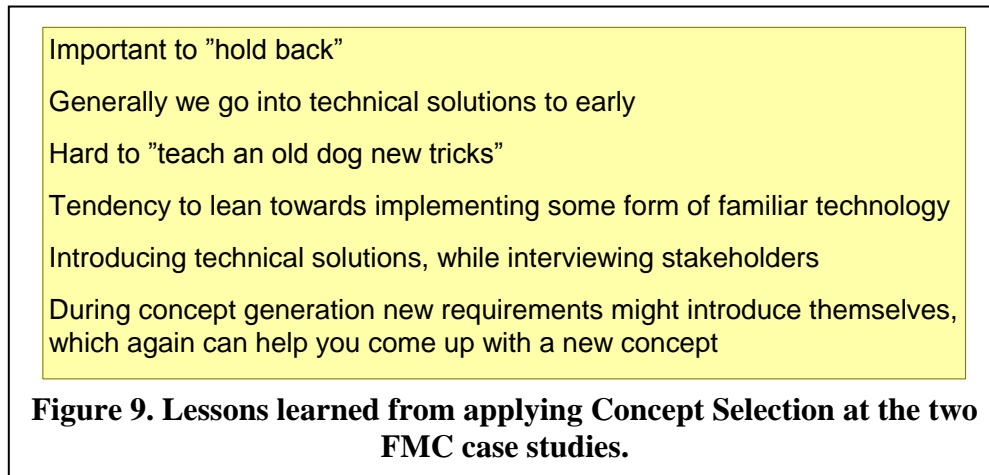


Figure 8. Pugh matrix for the Concept Selection of the connection between EDP and LRP.

The Pugh selection matrix, shown in Figure 8, shows that the wireless connection, concept 4, scores best overall, with only two disadvantages: this concept is less compatible with the past if it is implemented as sole connection and has less redundancy, and the engineering costs are higher since it is a revolutionary new design. The benefits are that it provides a robust connection that is easy to install without ROV.

Discussion of Concept Selection in Practice.

After the presentation of both case studies we discussed *Concept Selection* in practice in the Systems Engineering Study Group (SESG), <http://www.gaudisite.nl/SESG.html>. The discussion



was triggered by presenting the two first case studies. Especially the lessons learned at the end of the presentation, see Figure 9, were the starting point of the discussion.

The experience of the students when applying *Concept Selection*

is that the engineering team tends to skip all preliminary steps and to start realization as soon as possible. The course Fundamentals of Systems Engineering emphasizes the importance to understand the needs and problems of stakeholders before being biased by technical solutions. The existing culture conflicts with this approach, it is hard to "teach an old dog new tricks".

The sub sea domain tends to be rather conservative; implementations with familiar technologies are favored. Many stakeholder interviews center on introducing technical solutions, despite the intent to work from needs and requirements. An interesting side effect is that discussions of solution concepts uncover new requirements.

The discussion in the SESG was initiated by asking the following three questions:

1. Do you apply *Concept Selection* techniques in your company?
2. If yes, what are the benefits and success stories; If not what are the road blocks?
3. How can *Concept Selection* techniques be introduced in a practical way?

Application of Concept Selection in companies

Concept Selection is not widely applied in the companies. In one of the bigger companies it has been applied incidentally, with some success. Sometimes it is being applied because the formal process requires it. One of the most positive applications is where the *Concept Selection* matrix is used in communication with management and with customers. In this case the matrix is simplified, not too many alternatives and criteria, and traffic light colors are used to indicate the scoring (green means good, yellow means there is some issue, red means bad).

Benefits, success stories, and road blocks

When *Concept Selection* is prescribed by process or customer requirements then it appears that the engineering team goes through the motions, but without following its intent. A matrix is being produced, but is mostly for show, rather than adding value. When it is being used as intended then it brings several benefits:

- documentation for the future
- basis for discussion in project groups
- closer to an appropriate solution
- accountability of the engineering team for the solution
- visual communication tool
- ensures structural process

When *Concept Selection* is not being used then the following road blocks are mentioned:

- culture
- the believe that a problem and its solution are trivial
- not prescribed in process
- benefits need to be shown and proven
- management need to be convinced
- management lack of knowledge of these techniques
- political resistance, different perspectives of stakeholders
- hard to convince experienced engineers (“old dog story”)

How to introduce Concept Selection is a practical way?

The discussion resulted in the list of ideas below. Note that there is some tension between ideas provided here and previous remarks made in response to previous questions. For example, when *Concept Selection* is part of the company processes, then it is being applied to satisfy the system rather than following the intent. That doesn't mean that embedding it in the processes in itself is bad, but apparently more is needed to make it work.

- Use it to present decisions to customers or managers

- Offer company wide training
- Show the bottom-line benefits
- Integrate *Concept Selection* in the development processes (standardization)
- Show convincing examples from real projects to management
- Facilitate workshops in real projects
- Do pilot project
- Create an environment for Systems Engineering (fostering the discipline, for instance via networking)
- Create an environment for longer term R&D, where time pressure doesn't kill new insights, ideas, techniques or methods

Results of more case studies

Some students from the next cohort also chose *Concept Selection* as subject. Their results are generally in line with the first two case studies.

Anders Ekholdt [Ekholdt 2010] applied Pugh Matrices also in the sub sea domain. He concludes that “*The Pugh matrix was found to be effective both as an evaluation tool and as a visual communication tool during the project. Benefits from the entire process were increased focus on the core need by capturing the essential concerns from the stakeholders.*”

Erlend Hognestad Seppola [Seppola 2010] combined modeling techniques and the application of Pugh matrix to perform *Concept Selection*. The opinion of the stakeholders about the Pugh matrix was quite positive: “*Everyone who saw the Pugh matrix found that relevant as a comparison model and found the criteria and the concept selection accurate*”. The Pugh Matrix captured all separate phases of the system into one system. That was why the preferred concept was considered a better system even though some of the phases were more costly than others.

Vebjørn Nedrestøl describes the resistance of experienced engineers to apply SE techniques such as Pugh Matrix. He also did some research on the amount of changes late in projects and the related costs. He shows, supported by a number of historical cases that late changes contribute significantly to the cost. He also shows that a better understanding early in the project may prevent such costs. Today’s sealing solutions could not handle our requirements for the kind of Telescopic Joint the project needed. The applied SE techniques and the Pugh matrix helped to discover this shortcoming early in the project. Afterwards the team that was developing a Safety Joint gained a lot from the technology and qualification work that had been done.

Summary and Conclusions

Concept Selection is one of techniques being taught in the Master Systems Engineering. The technique is applied when needs of stakeholders and requirements have been collected. The idea behind *Concept Selection* is that a good solution is achieved by analyzing a few alternating designs and comparing them by a set of criteria that fits the problem.

We observe in practice that managers and engineers tend to skip this phase and prefer to jump into a realization. The perception is that *Concept Selection* is time consuming; spending time on it can not be afforded.

From the discussions in the SESG it became clear that we have to show more clearly how *Concept Selection* improves the development effort, rather than slows it down. We need to show real examples and we also have to show the bottom line impact of applying *Concept Selection*. Too often we show the technique itself, without translating the impact in bottom line figures.

Based on these observations we continue research on *Concept Selection* by using case studies. The cohort of master students starting January 2011 will again deliver a number of reports on the use of Pugh matrices.

Acknowledgements

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Biography



Gerrit Muller, originally from the Netherlands, received his Master's degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as a manager of systems engineering, returning to Philips (Research) in 1999. Since 2003 he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008 he became a full professor of systems engineering at Buskerud University College in Kongsberg, Norway.

All information (System Architecture articles, course material, curriculum vitae) can be found at: Gaudí systems architecting <http://www.gaudisite.nl/>



Halvard Bjørnsen received his Bachelors Degree in Mechanical Engineering from Buskerud University College in 2006. In the fall of 2006 he started working at FMC Technologies as a part of the Systems Engineering Master Program at Buskerud University College and Stevens Institute of Technology. Initially a designer he later became a project engineer in FMC Technologies' Intervention/ Connection department. He received his Master Degree in Systems Engineering in 2009, and got a full position as a project engineer in FMC in 2008 before completing his Masters.



Dag Jostein Klever received his Bachelor Degree in Mechanical Engineering from Buskerud University College in 2006. Later in 2006 he was hired at FMC Technologies as a product responsible engineer. At the same time he entered the pilot program for the industry master program in Systems Engineering. This program is collaborated between the industry, Buskerud University College and Stevens Institute of Technology. He received his master of science in systems engineering from Stevens Institute of Technology, USA in 2009. Currently he is working at FMC Technology as product responsible engineer for well integrity equipment in the Well Access Systems DPT.



Michael Pennotti is Distinguished Service Professor and Associate Dean for Academics in the School of Systems and Enterprises at Stevens Institute of Technology. Before joining Stevens in 2001, Mike spent twenty years in systems engineering practice and leadership at Bell Laboratories, and another ten a member of the senior leadership teams of three different AT&T businesses. Since joining Stevens in 2001, Mike has helped develop the SDOE Program into the largest systems engineering graduate program in the U.S.. He is a member of the International Council on Systems Engineering and a senior member of both the IEEE and the American Society for Quality. He holds Ph.D. and MS degrees in Electrical Engineering from the Polytechnic Institute of New York, a BEE from Manhattan College, and is a graduate of the AEA/Stanford Executive Institute for Technology Executives.