Stefan BERG
Regional Manager Six Sigma
Tenneco Inc.
Edenkoben, Germany

THE COMBINATION OF THE SIX SIGMA AND DESIGN FOR SIX SIGMA WORKFLOW INTO AN INTERACTIVE PROCESS MODEL FOR HOLISTIC IMPROVEMENT ON PRODUCT AND PROCESS DOMAIN

Summary. Six Sigma and Design for Six Sigma (DFSS) are both very successful strategies for the enhancement or the development of new products. Many researchers have studied Six Sigma and DFSS over the years and there is consensus that companies do benefit from applying both methodologies together. A clear understanding of when to use which approach is essential to optimize the potential of both methodologies. In general, the area of focus for projects is either on the process domain or on the product domain. By expanding the improvement scope of both domains, interactions of the Six Sigma and Design for Six Sigma methodology for improvement are possible and lead to enhanced process models for improvement, facilitating a holistic improvement approach.

102 implemented projects from Tenneco Inc.'s global engineering centers have been analyzed and grouped according to this model.

Keywords: Six Sigma, Design for Six Sigma, Lean Six Sigma, Lean Product Development, Engineering

POŁĄCZENIE ZADAŃ SIX SIGMA ORAZ DESIGN FOR SIX SIGMA W PROCESOWYM MODELU INTERAKTYWNYM DLA CAŁOŚCIOWEJ POPRAWY W DOMENIE PRODUKTOWEJ I PROCESOWEJ

Streszczenie. Six Sigma oraz Design for Six Sigma (DFSS) stanowią dwie bardzo skuteczne strategie wspomagania i rozwoju nowych produktów. Wielu badaczy,

analizując przez lata Six Sigma oraz DFSS, doszło do wniosku, że przedsiębiorstwa czerpią korzyści ze stosowania obydwu metodologii jednocześnie. Klarowne rozumienie, kiedy należy wykorzystywać, które z tych podejść, jest kluczowe dla uzyskania optymalnego potencjału metod. Obszar projektów stanowią zarówno procesy, jak i produkty. Poprzez rozszerzenie zakresu poprawy obu tych dziedzin, możliwa staje się poprawa interakcji Six Sigma oraz Design fo Six Sigma, co prowadzi do stworzenia lepszych modeli uwzględniających podejście charakteryzujące poprawę w rozumieniu całościowym.

Według modelu zaprezentowanego w niniejszym artykule przeanalizowano i pogrupowano 102 projekty wdrożone w globalnych centrach firmy Tenneco Inc.

Słowa kluczowe: Six Sigma, Design for Six Sigma, Lean Six Sigma, odchudzony rozwój produktu, inżynieria

1. Introduction

Six Sigma – DMAIC was developed by Motorola in the 1980s as an enhancement of their Total Quality Management (TQM) approach focusing on quality improvement. Companies such as General Electric (GE) developed the concept even further and extended the application of Six Sigma tools to their entire business, including the development of new products focusing on financial gain and customer satisfaction. From an engineering point of view, Six Sigma offers a rigorous, data-driven procedure for process and product improvement.[1]

A) Product design baseline not ok.
- Improvement of function.
- Manufacturing process not involved.

B) Process baseline nok.
- Improvement of process performance.
- Product design not involved.

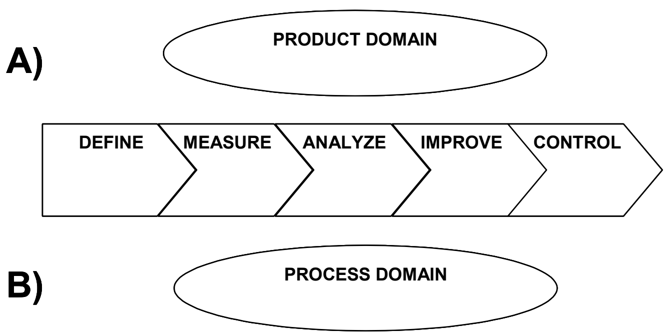

Fig. 1. Scenario 1: DMAIC methodology – structured improvement of products and processes
Rys. 1. Scenariusz 1: metoda DMAIC – strukturyzowana poprawa produktów i procesów

[1] Brand J., Berg S., Garcia P.: Using Six Sigma concepts in the engineering process of automotive suppliers: Analysis of an acoustical test bench, SAE 2007-07AE191, Detroit.

Design for Six Sigma (DFSS) targets the concurrent development of a new or radically redesigned product and all of the processes (Research, Design, Production, Logistics and Distribution, Service and Sales) to enable the product to achieve Six Sigma business performance. The DFSS process can be seen as an algorithm, an iterative team-oriented process, to design and develop solutions in a structured and data driven way.[2]

This engineering vision can be accomplished by integrating design best practices, reducing design vulnerabilities, permitting a balance between creativity and discipline with accountability and flexibility.

The phases of this methodology for designing products (goods, information or services) or processes are Define, Measure, Analyze, Design, Verify (DMADV), linking proven methods and tools taken from the Quality Management and Quality Engineering toolbox.[3]

A) Product baseline not ok.
- Baseline can not be re-designed or improved to reach customer needs / targets.
- New product design needed.
- Existing manufacturing process sufficient therefore not involved.

B) Process baseline not ok.
- Can not be re-designed or improved to reach customer needs / targets.
- New process design needed.
- Existing product design sufficient therefore not involved.

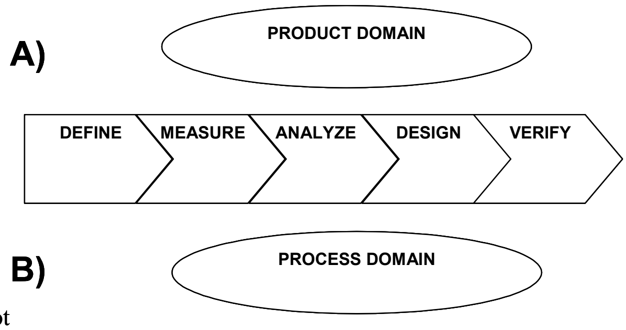

Fig. 2. Scenario 2: DMADV methodology in the context of new product or process design
Rys. 2. Scenariusz 2: metoda DMADV w kontekście projektowania nowego produktu lub procesu

Implementing and utilizing Six Sigma in an engineering environment is accompanied by the question whether Six Sigma or Design for Six Sigma is the right approach.

Many companies implemented Lean and Six Sigma programs in their manufacturing areas and a Design for Six Sigma program in their engineering departments. Due to the difference in tools and methodology and targeted audience, both programs run more parallel than cohesive. Many companies are successful with Six Sigma but are having difficulties with their Design for Six Sigma deployment.[4]

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[2] Raisinghani M.S., et al.: Six Sigma: Concepts, tools and applications. "Industrial Management and Data Systems", 2007, vol. 105, no. 4, p. 491-505.
[3] Yang K., El-Haik B.S: Design for Six Sigma. Mc Graw Hill, New York 2009, p. 86-100.
[4] Berg S.: Using Six Sigma throughout the product life cycle. Presentation at IQPC Conference, Berlin 2006.

The conclusion from previous research on whether to use Six Sigma or Design for Six Sigma suggests that companies should apply both methodologies simultaneously, following clear project selection criteria. A major departure from existing product design guidelines would be an application for the Design for Six Sigma approach, where an incremental product improvement or enhancement would be a DMAIC Six Sigma case.[5]
The focus of research and publications in this context is on the product domain, focusing on product improvement or development of new products.

2. Product domain versus process domain

By definition the improvement focus in product engineering is on the product itself. However to develop best in class products in a very competitive environment may not only rely on a robust and data driven design methodology. The engineering process framework needs to be best in class, too in order to support and enable improvement efforts on the product domain.

Looking at the process domain in engineering, it has been shown that Six Sigma and Lean principles can be applied on engineering processes as well. In particular testing and measurement routines in engineering benefit from a combined Lean and Six Sigma approach.[6]

The Lean improvement focus targets reduction of lead time, variation and waste, complemented by the Six Sigma focus, looking at the quality of the measurement results.[7]

Table 1
Complementary improvement focus for Lean and Six Sigma for an engineering process – example testing and measurement process improvement

Lean process improvement focus:	**Six Sigma improvement focus:**
– Reducing number of process steps and lead time.	– Improving reliability and quality of results.
– Standardization of documentation and templates.	– Improving stability and accuracy of measurements.
– Improving scheduling and planning.	– Improving linearity and bias.
– Improving of information flow and access. Clear flow information.	– Reducing variation due to repeatability and reproducibility.
– Improving visual management.	– Introducing process controls.

Looking at the challenges and opportunities during the development of new products there are multiple requirements in the product domain as well as in the process domain, at the

5 Antony J., Banuelas R.: Going from six sigma to design for six sigma: an exploratory study using analytic hierarchy process. 2003.
6 Berg S.: Using Six Sigma and DFSS to move the engineering culture from lagging to leading. Presentation at IQPC Conference, Amsterdam.
7 Baumann A., Garcia P., Kölsch R.: Six Sigma applied for transactional areas. SAE 2007-01-0535, 2007.

same time. Therefore it seems to be logical, to expand the product focus of a combined Six Sigma and DFSS approach to the process domain as well.

On a high level the following scenarios can be described by tab. 2.

Table 2
DMAIC and DMADV, as separate methodology to address improvement scenarios in engineering

Product domain		**Process domain**	
The existing product design does not perform to its customer expectations or engineering targets.		The existing engineering process or workflow does not perform to its customer expectations.	
Improvement possible and sufficient.	Improvement not possible or not sufficient – new product design required.	Improvement possible and sufficient.	Improvement not possible or not sufficient – new process design required.
	A new – innovative product needs to be developed, that is new to the company.		A new engineering process needs to be developed.
Methodology			
Six Sigma-DMAIC	DFSS DMADV	Six Sigma–DMAIC Combined with Lean principles (Lean Six Sigma)	DFSS DMADV
Scenario 1	Scenario 2	Scenario 1	Scenario 2

In this overview, Scenario 1 represents a traditional DMAIC case, where an isolated product or process improvement is possible and sufficient. Scenario 2 describes cases for the application of the DMADV methodology. Both scenarios focus either on product domain or on the process domain.

3. Research Hypothesis

In many real life situations, the separation of the improvement focus between the process domain and the product domain is not possible. By improving a product or developing a new product, a process enhancement or a new process development is implied to ensure desired product performance. On the other hand, a process improvement can imply a product design change as well.

Looking at the DFSS workflow in more depth (see figure 3), during the “Design” stage the manufacturing concept is agreed and during the “Verify” phase it is verified. This is certainly sufficient when the existing manufacturing technology can be used and the transfer into serial production is a standard step of the process.

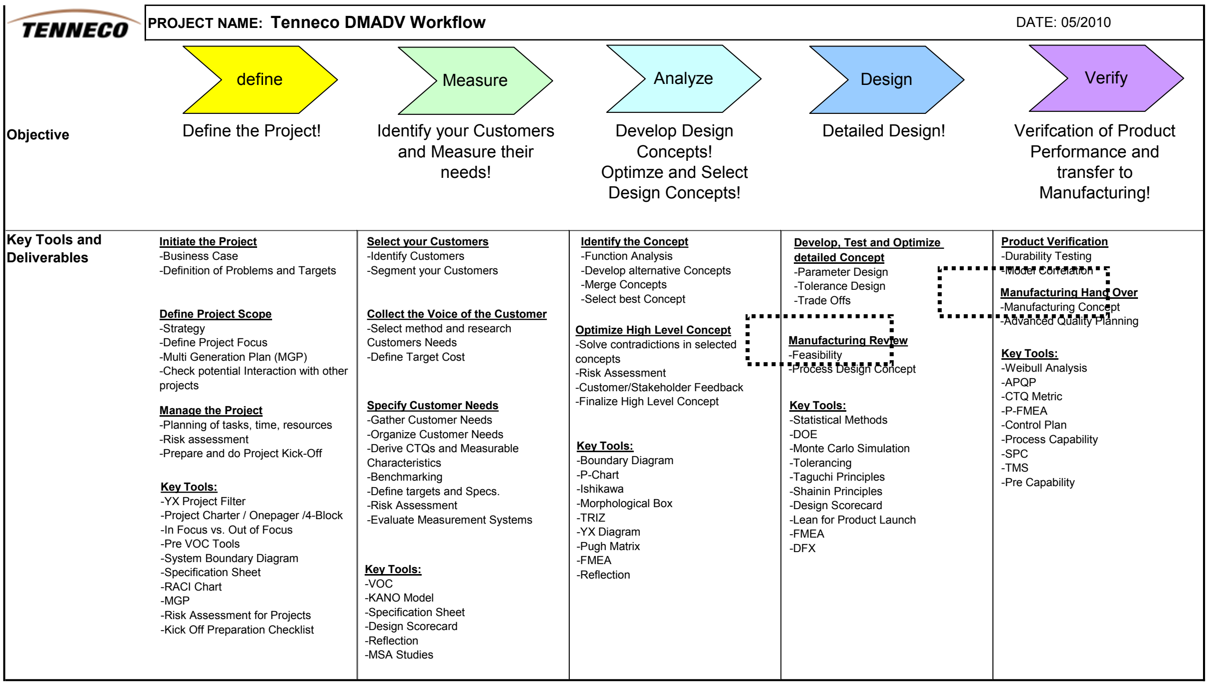

Fig. 3. DMADV – Workflow[8]
Rys. 3. DMADV – sekwencja zadań

In case the transfer of the new product to manufacturing is more difficult for example because, the existing manufacturing technology is not sufficient, a data and structured enhancement or the development of a new manufacturing process is needed. Therefore a DMAIC or a DMADV would be appropriate. In such a scenario the DMADV process on the product domain would interact with a DMAIC or DMADV process on the process domain. The interaction and the clear linkage between both domains offer potential for further synergies for product and process by better understanding potential trade offs between both domains.

H1: The Design for Six Sigma workflow (DMADV) on the product domain is not sufficient if the resulting activities on the process domain exceed a certain level of difficulty.

Another potential interaction scenario could start with a DMAIC improvement on the process domain. In this case an existing performance gap would be the subject of a Six Sigma project on a manufacturing or engineering process. During the "Improve" phase, based on the "Analyze" phase findings, improvement measures are developed, evaluated and implemented (see figure 4).

[8] Berg S.: Understanding differences between DMAIC vs. DMADV. Unpublished Tenneco internal presentation, Black Belt online training, December 2010.

If the process improvement can only be accomplished by changing the product design a DMAIC project on the product domain might be needed in case the change has a certain degree of complexity.

H2: The Six Sigma workflow (DMAIC) either on the product or product domain is not sufficient if the resulting activities on the other domain exceed a certain level of difficulty.

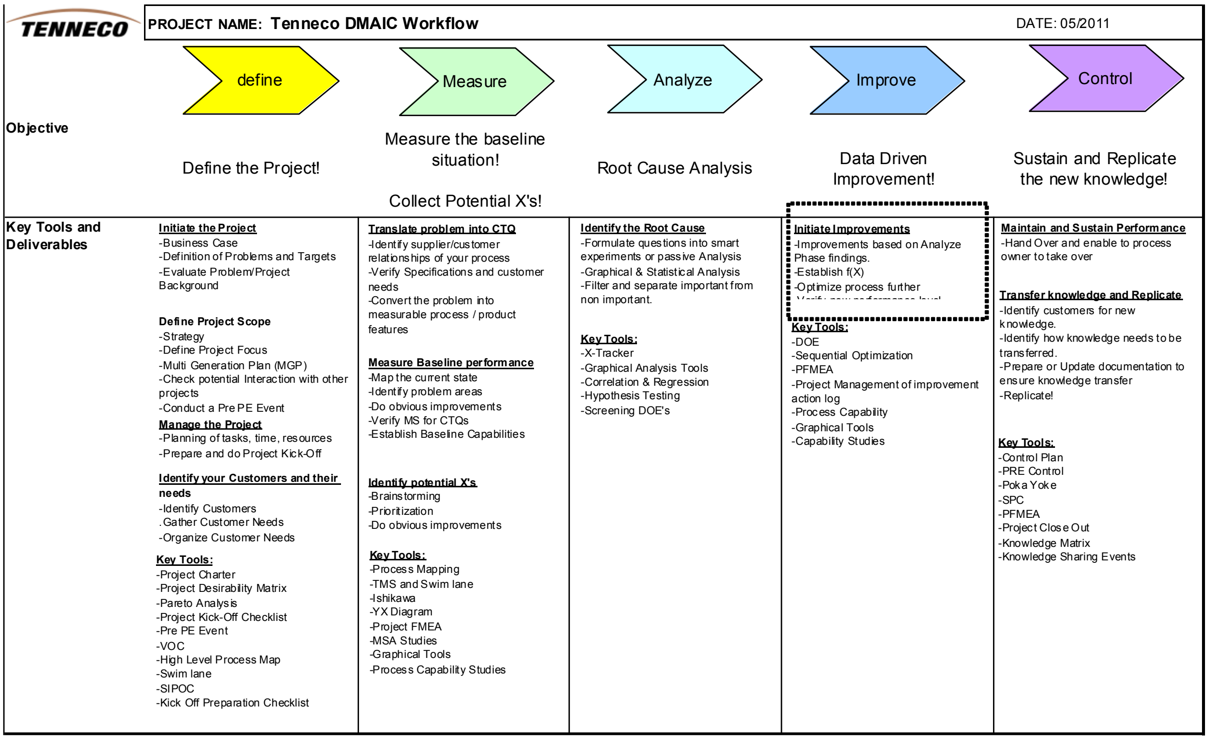

Fig. 4. DMAIC Workflow[9]
Rys. 4. DMAIC – sekwencja zadań

Based on the description of the potential shortages of applying both methodologies either on the product or process domain, the following interaction can be defined by tab. 3.

In such cases – both domains, product and process, interact with each other and so do the Six Sigma and DFSS methodologies, resulting in three additional scenarios that describe the interaction between the DMAIC and DMADV process models on the product and the process side.

[9] Berg S.: Understanding differences between DMAIC vs. DMADV. Unpublished Tenneco internal presentation, Black Belt online training, December 2010

Table 3

DMAIC and DMADV interaction models and scenario definition

Interactions between product and process domain					
Improvement of product requires a process improvement or vice versa.		New product design requires a process improvement.		New product design requires a new manufacturing process design.	
Methodology					
Product	Process	Product	Process	Product	Process
DMAIC	DMAIC	DMADV	DMAIC	DMADV	DMADV
Scenario 3		Scenario 4		Scenario 5	

Scenario 3 – Process Model for DMAIC-DMAIC interaction on product and process domain

In this situation, as described in table 3 above, the baseline situation is a performance gap either on the product domain or on the process domain. To close the performance gap a DMAIC approach is sufficient but affects the other domain. Therefore the improvement on the product requires a structured improvement on the process side or vice versa. However looking at both domains at the same time adds a third domain which can be defined as the Process – Design interaction. The interaction between both domains offers further potential for improvement by the understanding trade offs while improving product and process hand in hand.

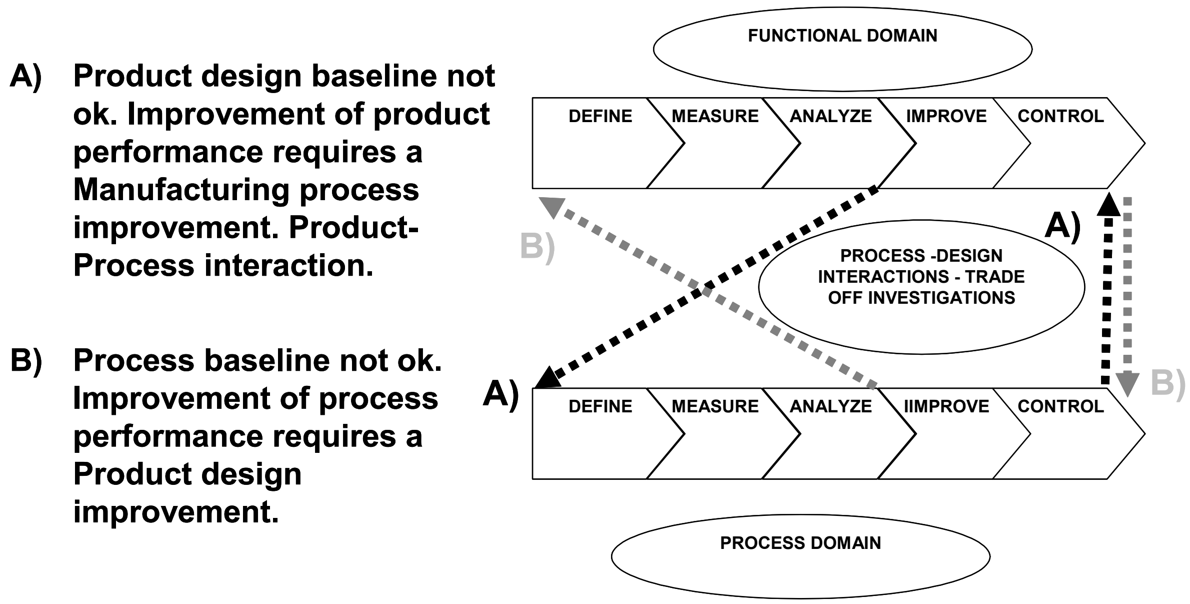

Fig. 5. Scenario 3 – DMAIC – DMAIC interaction on process and product domain
Rys. 5. Scenariusz 3 – DMAIC – DMAIC interakcja w zakresie procesu i produktu

Scenario 4 and 5 – Process Model for DMADV – DMAIC and DMADV – DMADV interaction on product and process domain.

Following the DMADV process on the product domain results in a new product. If this newly developed product can be manufactured on existing technology it is according to the introduced classification a scenario 2 case. Often a new product can not be transferred one to one to existing manufacturing processes and technology.

If the new produced requires a process enhancement following a DMAIC approach we can describe this as a scenario 4 – a DMADV – DMAIC interaction.

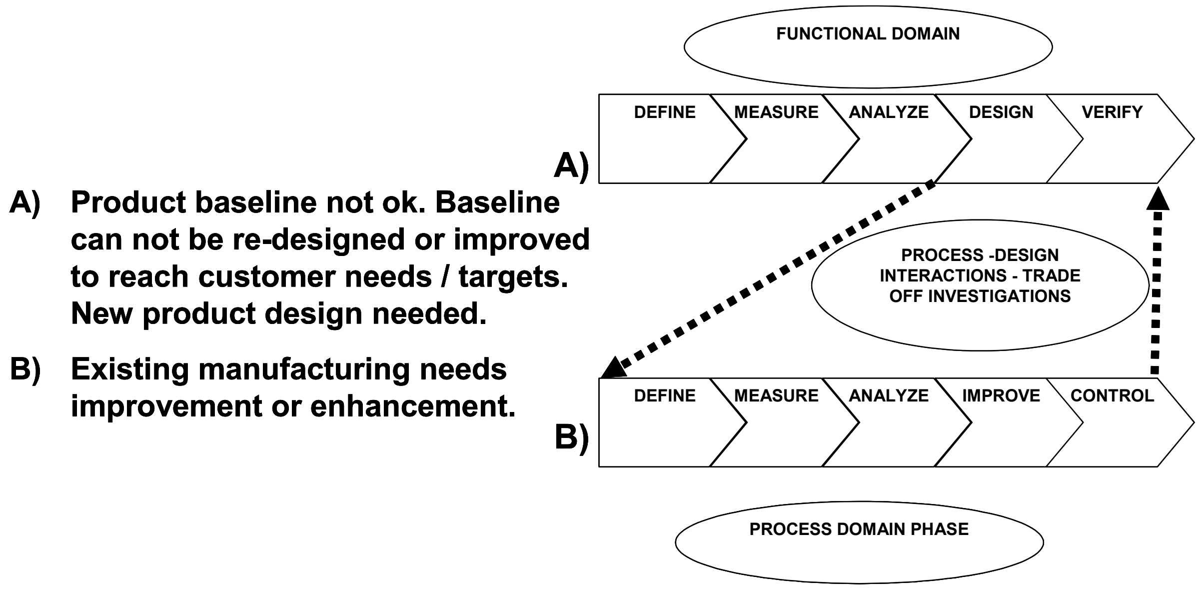

Fig. 6. Scenario 4 – DMADV – DMAIC interaction on product and process domain
Rys. 6. Scenariusz 4 – DMADV – DMAIC interakcja w zakresie procesu i produktu

As a scenario 5 we can define a case when the new product requires a new manufacturing process or the existing manufacturing process is not sufficient or can not be enhanced.

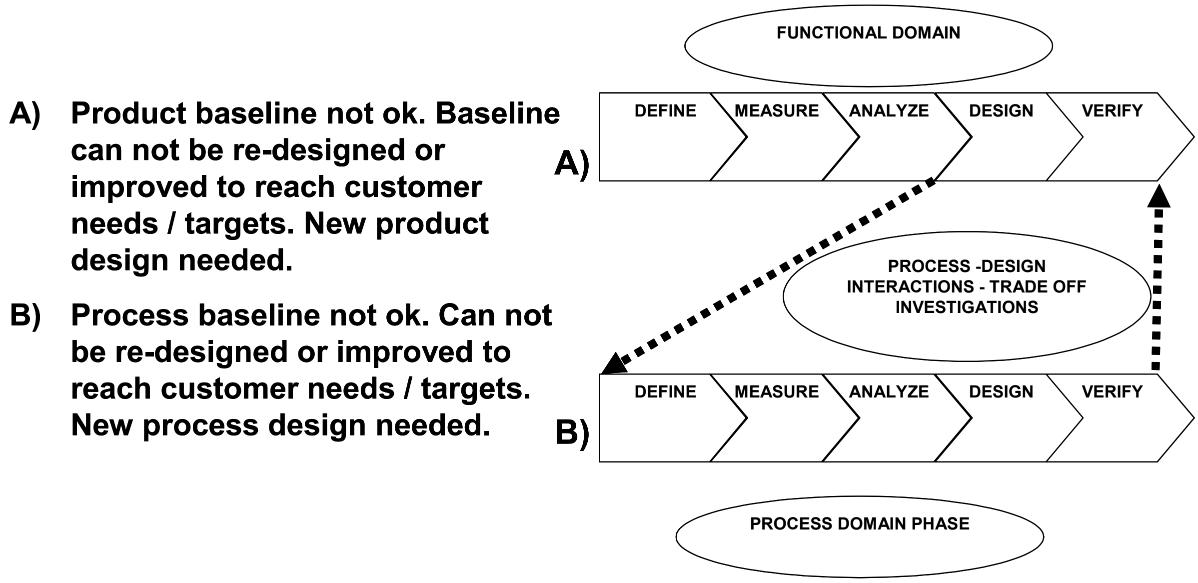

Fig. 7. Scenario 5 – DMADV – DMADV interaction on product and process domain
Rys. 7. Scenariusz 5 – DMADV – DMADV interakcja w zakresie procesu i produktu

Scenario 3-5 describe the possible Six Sigma and DFSS interactions in case improvements on the process and the product domain are not independent from each other. This linkage is not obvious and those interactions complement both methodologies and can generate further opportunities in the development work by understanding the trade offs between product and process.

Product and Process development:	**Product improvement:**
– Potential trade-offs opportunities between product and process domain become more visual. – A clear understanding of trade-offs provides further improvement potential and strengthen the new product concept further.	– Product improvements reveal gaps or further improvement potential in current engineering processes. – Engineering improvements become subject of a new Lean Six Sigma activity or a new process development (DMADV).

4. Research methodology

The data to test the proposed research hypotheses was collected via a single case study approach. Therefore the documentation of 102 implemented Six Sigma projects at Tenneco Inc. were evaluated and categorized, according to the proposed scenario model. Tenneco Inc. is a global first tier supplier to the automotive industry, headquartered in North America, with more than 22.000 employee world wide.

The studied projects were implemented in four Tenneco engineering centers in North America (43 projects) and Europe (59 projects) during 2008 and 2010.

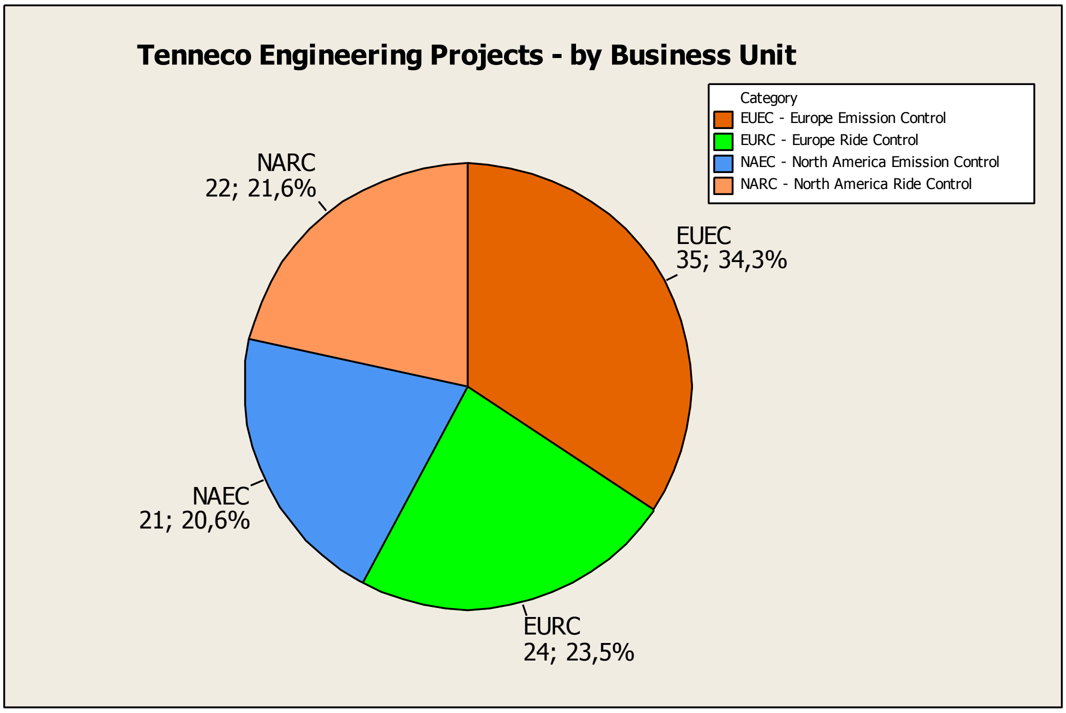

Fig. 8. Breakdown of evaluated projects by location and business unit
Rys. 8. Podział ocenianych projektów według lokalizacji i jednostki biznesu

The selected projects represent a global picture of implemented projects at Tenneco with a split of 53,8% from Europe and 42,2% from North America. The projects also represent both business units from Tenneco Ride Control (RC) 45,1 % versus 54,9 % from Emission Control (EC).

5. Results and discussions

The project documentation was evaluated and grouped. For the grouping two categories have been defined.

1. Project focus area
2. Six Sigma scenario (acc. to table 2 & table 3)

By projects focus area

According to the focus area of the Six Sigma project the following categories have been defined:

Project focus area	**Definition**
Engineering & Testing standard	Project Focus on improving or designing a new engineering process for example: – Better correlation between simulation and measurements of predictive tools like acoustic simulation – Repeatability & Reproducibility improvements on test benches
Product improvement	Project Focus on improving functional performance, for example: – Acoustic and backpressure optimization of muffler concept
Knowledge gap	Project focus on closing an obvious knowledge gap, for example: – Impact of leakage due to converter mats in hot end applications
New product	Project focus on developing new and innovative products, for example: – Electrical valve for acoustic application – Mixer design for heavy duty application
Process design	Project focus on developing new or enhancing existing manufacturing processes, for example: – New sizing tool design for post calibration

The biggest group of implemented projects at Tenneco focuses on the improvement, enhancement or development of engineering & testing procedures.

Those projects represent 47,1% or 48 projects. With 31,4% or 32 projects, the second driver is the "Product Improvement". Knowledge Gaps represent 9,8% of the projects, where new products and new process together represent only 11,7 % of the evaluated projects.

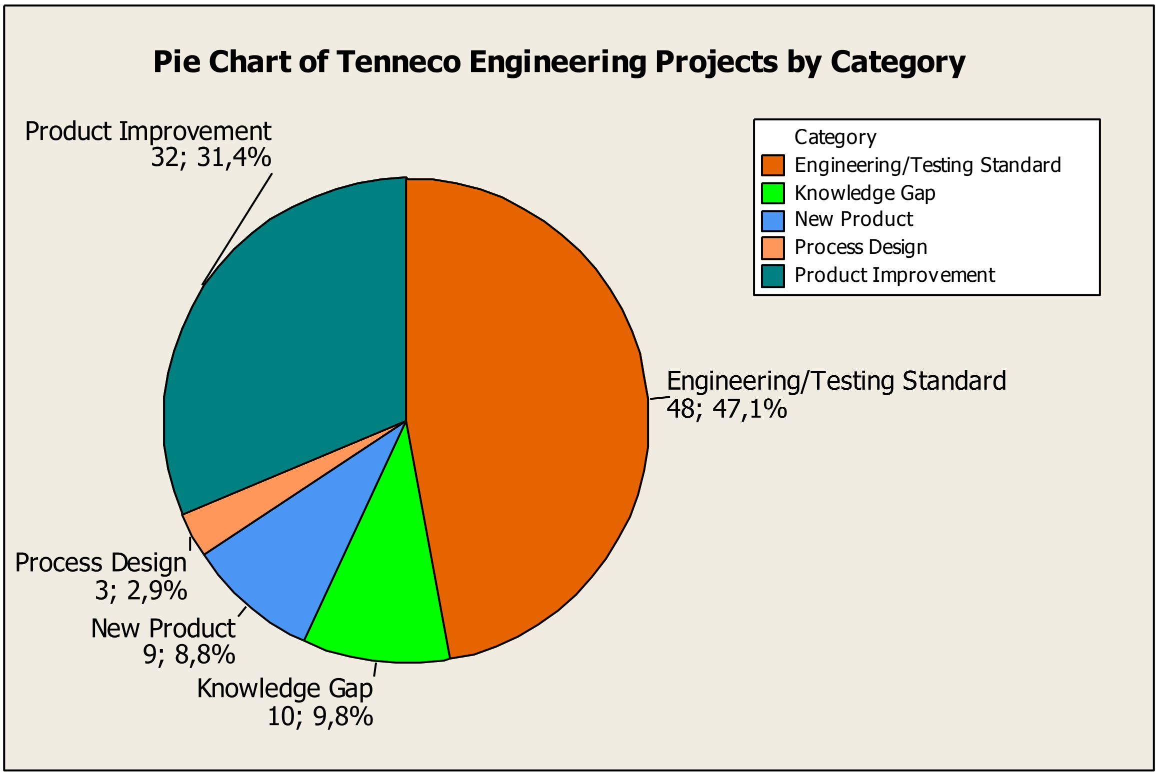

Fig. 9. Project categorization of evaluated projects by project focus area
Rys. 9. Kategoryzacja ocenianych projektów według obszaru tematycznego

By Six Sigma scenario model (acc. to table 2 & table 3)

Combining table 2 and table 3, the following scenario summary can be listed (tab. 4)

Table 4

Six Sigma and DFSS scenario models

Scenario	Product Domain		Process Domain
Scenario 1	DMAIC	or	DMAIC
Scenario 2	DMADV	or	DMADV
Scenario 3	DMAIC	and	DMAIC
Scenario 4	DMADV	and	DMAIC
Scenario 5	DMADV	and	DMADV

Out of the 102 evaluated projects, 77 projects focused either on the product or process domain using DMAIC workflow and fall under a scenario 1 category.

All DMADV projects on the product domain triggered further improvement or new development work on the process domain; therefore we could not count a scenario 2 example. 25 of 102 projects can be categorized using the introduced scenario model three, four and five. The majority of those can be described as a scenario 3 project, where only one project was a scenario four and five can be defined as scenario 5.

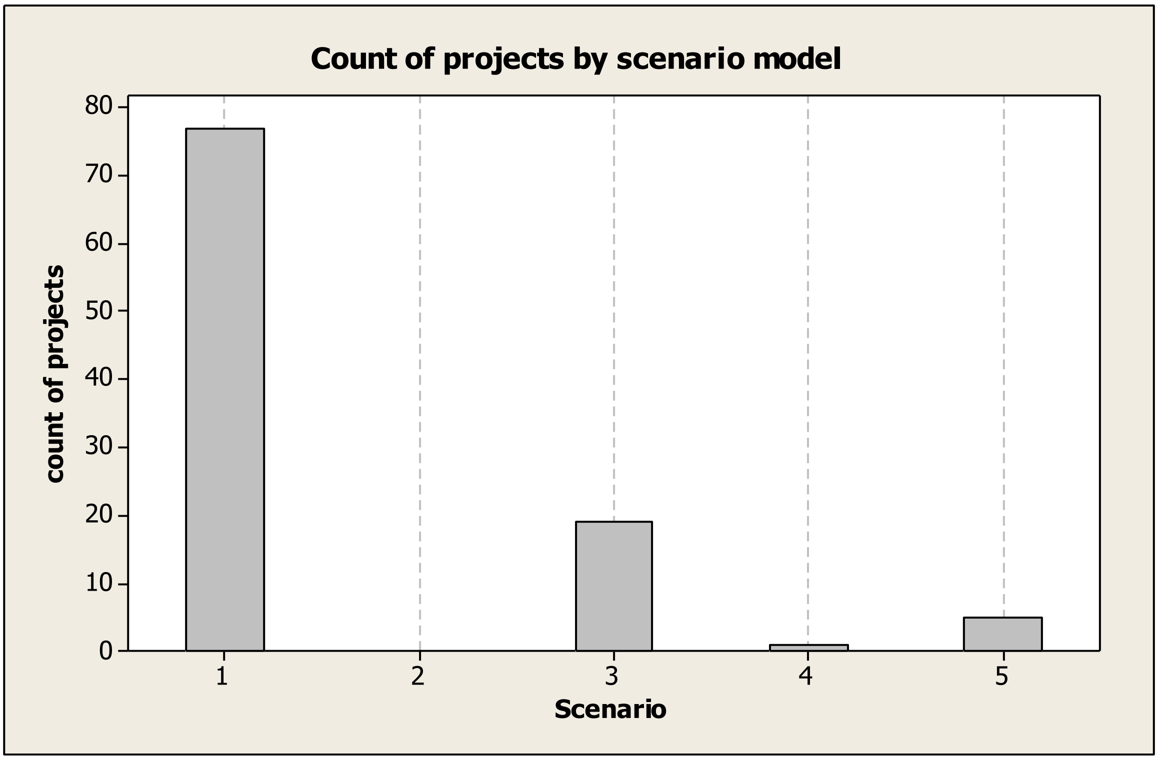

Fig. 10. Count of all projects by scenario model
Rys. 10. Obliczenia dla wszytskich projektów według modelu scenariusza

Summary – by Six Sigma scenario model and project focus area

Engineering and testing standards

48 projects have been implemented. 40 projects focused on the improvement of an existing testing process using a DMAIC approach and so can be counted as scenario 1. Eight projects were triggered by increasing engineering requirements from a new product development or enhancement. One project required a new design following a DMADV methodology (Scenario 4) where the remaining seven projects were worked on using a DMAIC workflow (Scenario 3).

Product Improvement

32 projects were focusing on a product improvement using a DMAIC workflow (scenario 1). 12 projects were triggered by manufacturing process DMAIC projects (scenario 3).

Process design

Three implemented projects represent two process enhancements (Scenario 1) and one process enhancement triggered by a new product development (Scenario 5).

New product

Nine projects have been implemented. Five projects followed a DMAIC workflow and focused solely on the product domain (scenario 1).The remaining four implemented projects followed a DMADV approach for the new product design. All four DMADV projects triggered a DMADV project, for a new manufacturing process, which are not yet implemented. Those four can be counted as a scenario 5.

Knowledge gap

Ten projects have been grouped as knowledge gap projects. Those projects used a DMAIC process to close a knowledge gap either on the product or process domain. No interactions identified, therefore Scenario 1.

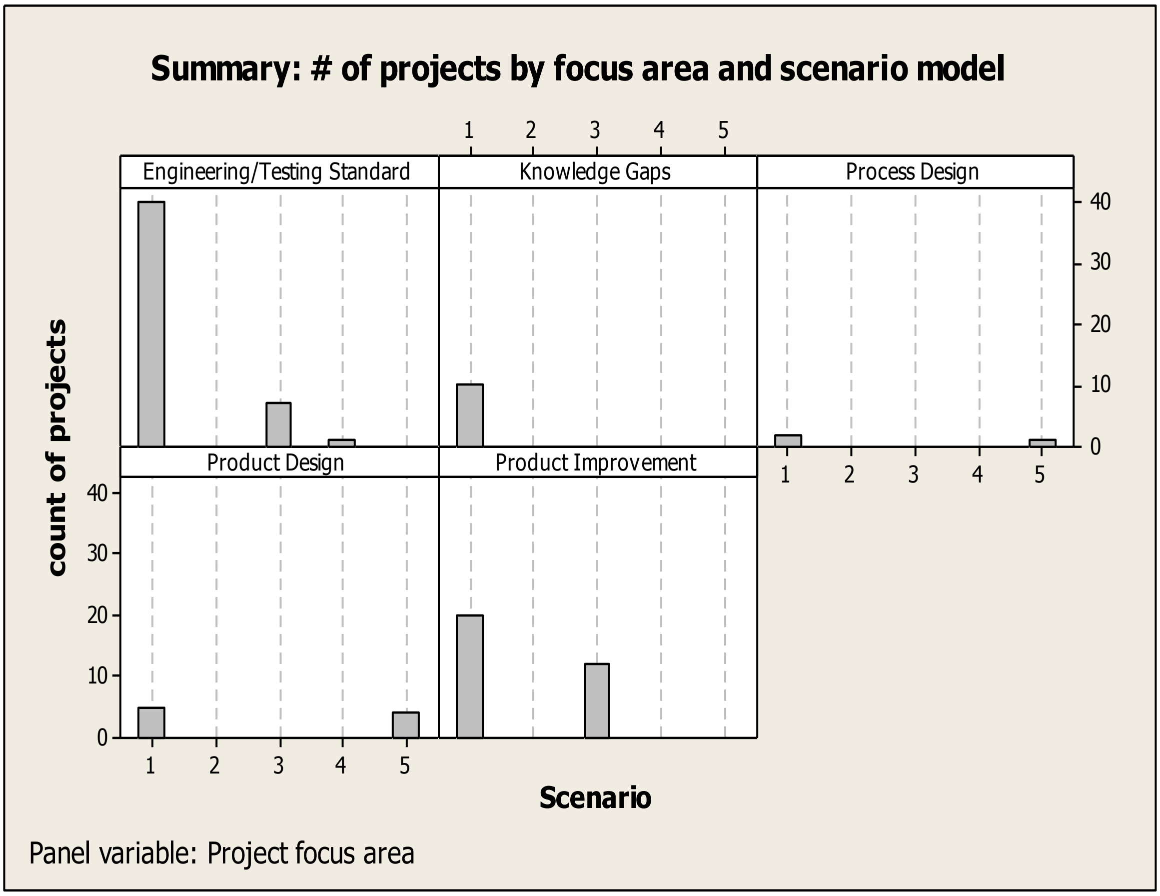

Fig. 11. Summary – count of all projects by focus area and scenario model
Rys. 11. Podsumowanie – obliczenia dla wszystkich projektów według obszaru tematycznego i modelu scenariusza

Table 5

Summary of analyzed engineering projects – category vs. scenario model

Scenario	Engineering/Testing Standard	Product Improvement	Process Design	Product Design	Knowledge Gaps	Total
1	40	20	2	5	10	**77**
2						**0**
3	7	12				**19**
4	1					**1**
5			1	4		**5**
Total:	**48**	**32**	**3**	**9**	**10**	**102**

6. Conclusion

Based on detailed analysis and evaluation of the engineering projects, this study concludes that the Six Sigma (DMAIC) and the DFSS workflow (DMADV) are well utilized methodologies and provide a robust framework for product improvement as well as product development. The DMAIC methodology is used to enhance product performance and to strive for process excellence in engineering. Both methodologies work very well when the improvement focus remains in the origin domain of the project (scenario 1 and scenario 2).

If the improvement focus goes beyond the original domain, both methodologies have limitations. If optimization is only possible by including both domains, it seems necessary to expand the traditional methodologies as defined by the situation.

The Design for Six Sigma (DMADV) workflow does not represent the needs for the process domain when the new developed product cannot be directly transferred to existing manufacturing processes. If the new product requires a new manufacturing technology (scenario 5) or a significant enhancement of the existing one (scenario 4) the DFSS workflow is not sufficient. All observed DFSS projects in this study were on the product domain and led to new DFSS projects on the process domain to ensure desired final product performance. Product and process improvements often go hand in hand. Scenario 3 describes the case when both domains interact and improvements to both have a certain degree of difficulty. This scenario was found in nearly 20% of the studied projects.

Regarding the limitations, this researcher studied projects implemented in engineering departments at an automotive first tier supplier in Europe and North America, therefore the research findings may be limited in their application to other industries and organizations. Similar studies in different industries may lead to different conclusions. Future research can expand the focus to different industries and commodities.

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Recenzenci: Dr hab. Agata Stachowicz-Stanusch, prof. nzw. Pol. Śl.
Dr hab. Agnieszka Sitko-Lutek, prof. UMCS