Quantifying the benefit of introducing Systems Engineering Processes - Myth or Reality?

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Abstract. In the past years the automotive industry had to face, especially in the field of electric/ electronic, an increase in complexity. To be able to keep highest quality standards BMW Group had to restructure its existing processes within electric/electronic development according to these new challenges. A Change Program was set up to shift those development processes towards a system orientated development.

For commercial driven companies an evaluation of cost vs. benefits is a prerequisite for approval and execution of such a change program. Therefore a business case was necessary. At the beginning of the change program a statement of anticipated likely impacts had to be made. At the end of the change program predicted impacts had to be validated. The approach taken was based on an aggregation of evaluations performed by the different subprojects of the change program.

This paper is illustrating – based on the experiences of a subproject (Configuration Management) – the approach taken to model and evaluate a business case at the beginning and the end of the change program. An example using neutralized data from BMW Group is demonstrating the approach. Lessons learned and success factors implementing the approach are discussed.

Evaluating or even quantifying the value of Systems Engineering Processes within product development is discussed within the SE community for quite a while, with very different positions. This paper aims at making a contribution to this discussion.

Introduction

Performance driven commercial companies ask critically about the value of new processes. However, the proof is a complicated thing to do.

In the case of Systems Engineering Processes the evaluation is, because of their interconnectivity and complexity, more complicated as in the case of standard business processes. A number of activities within INCOSE aim at proving the value of SE for development processes. They also benchmark the impact of the quality of SE efforts and the identification of the optimum level of SE efforts in the development costs [Honour, 2005].

The objective of this paper is to make a contribution to this subject by providing a field report. It is about the experiences on setting up a business case for a Change Program within electric/ electronic development processes at BMW Group. In general it is difficult to find information about methodologies applicable for evaluating the benefits of new processes. Only few literature deals with the question of how to build up a transparent and credible business case [Schmidt, 2002].

This paper is structured into four main parts:

1. Some background concerning electric/electronic development at BMW Group
2. The business case approach at the beginning of the Change Program
3. The business case approach at the end of the Change Program
4. Lessons learned and success factors derived from applying the business case approach

Background - Setting up a Change Program for system oriented development processes within electrics/electronics

Fundamental changes within the automotive industry. The intensive competitive environment and new technological possibilities lead to more product models, more product variants and more product individualization possibilities – and in the same time to more electrically/ electronically controlled functions. By this, the consequence is a growing amount of components that interdepend on each other – and so a dramatic increase of complexity, which the product development departments have to face. [see Figure 1]

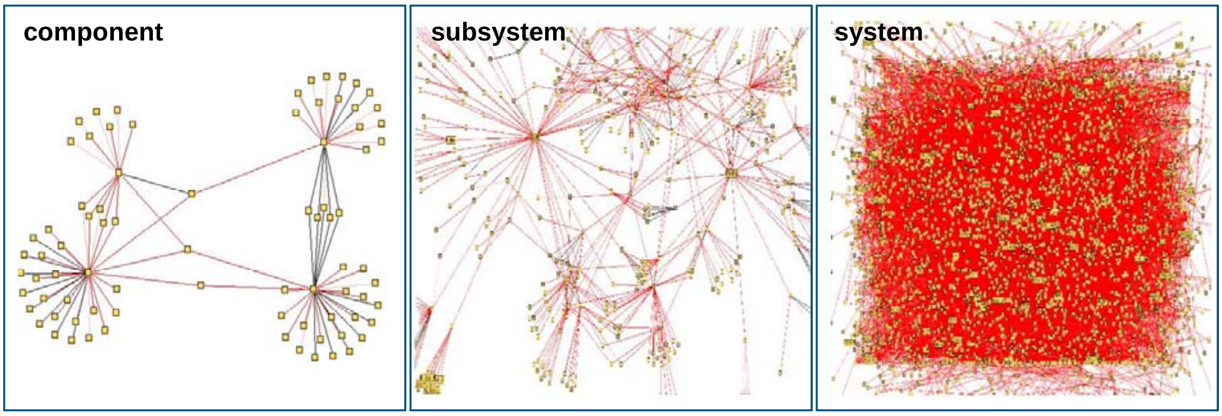


Figure 1. Complexity in today's automobiles – an increased number of components and interrelationships (schematic view)

Inherent problems of the situation lie in risks arising from low product quality due to development processes being unable to cope with the high complexity of electric/electronic subsystems. The automotive industry is very sensitive to those risks, because consequential costs like warranty charges or image loss and with that a decline in sales, may deeply affect the success of an OEM or a supplier. As a consequence, BMW Group some years ago started to rethink its development processes within electrics/electronics in order to be able to cope with the steadily increasing complexity of electric/electronic subsystems.

Systems Engineering or "system oriented development" as solution approach. For this challenge a Change Program was set up to conceptualize, implement and roll-out new development processes within electrics/electronics. The development paradigm should be shifted to a system driven development, starting at the very beginning of the development process. The most important objectives were:

- stabilization of development processes
- efficiency of development processes
- prevention of risks
- ability to innovate radically

To achieve theses objectives several subprojects had been defined. The subprojects covered typical systems engineering processes like requirements engineering and management, system design, system integration, verification and validation, project management, risk management, and configuration management, but also supporting processes like quality management or process management. The focus was set on critical processes to enable BMW Group to successfully design and integrate the growing number of electrical/electronical components (ECUs) – mostly developed and supplied by first and second tier suppliers – into a high quality electric/electronic system.

Setting up a Business Case – a conflict of conditions. In a commercial company like BMW Group the proof of economic benefit is crucial for the realization of such a Change Program. It is about the confrontation of the following questions:

- How much does it cost?
- What will be the benefit?

Answering these two questions is a difficult undertaking. Why that? [see Figure 2]

First: At the beginning of the Change Program an estimation about the anticipated impacts had to be made. But at that point the measures to be taken by the different subprojects were not known on a very detailed level. Only fuzzy assumptions could be used as a basis for estimating potential impacts.

Second: At the end of the Change Program the interest lied in proofing the anticipated impacts in a detailed evaluation. At that time, the measures developed in detail by the different subprojects were known very well and already implemented, or at least in a stage of implementation. But the evaluation had to deal with a complex structure of interacting measures and areas of impacts. In addition to that, there was still uncertainty due to the fact that not all measures were implemented or only started producing effects.

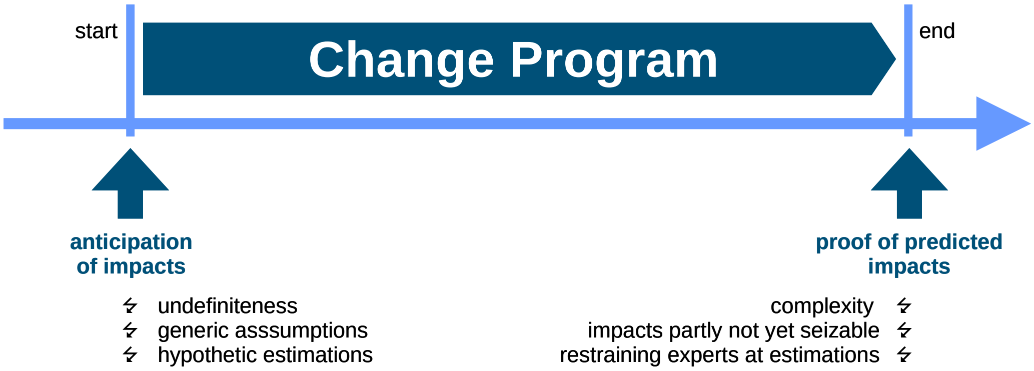


Figure 2. The business case at to points of time of the BMW Group Change Progam and its critical aspects for the evaluation (schematic view)

Besides, a business case is always a political issue. This might influence the results – especially when vague estimations have to be stated.

Despite fuzzy assumptions about measures, impacts and their relations evidence of economic efficiency had to be provided. The key to a credible business case is on the one hand using a pragmatic and well-founded approach making the effects of the taken measures transparent and quantitatively tangible, and on the other hand, it is the elegant handling of the fuzziness. The following sections will illustrate the approach chosen to set up a business case for the Change Program at BMW Group, what lessons learned have been made, and what recommendations could be derived for futures business cases.

Anticipation of benefits - the business case at the beginning of the Change Program

A business case as the basis for program assignment. At the beginning of the Change Program, a forecast of the supposable costs and economic benefits had to be made for each subproject and on a program level. This was a prerequisite for program and subproject approval and budget planning. From the beginning on, the figures were linked to the budget planning of the product development projects. Thus pressure was put on the product development projects to adopt the new processes, but also on the subprojects to provide the new processes for the product development projects in time and in appropriate quality.

According to the structure of the Change Program consisting of subprojects as mentioned before the approach chosen was a bottom-up. Each subproject had to give estimations of its costs and benefits. The results were aggregated on program level. In order to simplify the aggregation the subproject figures were added, possible multiple inclusions of effects were not considered, although this “falsified” the figures on program level.

In the following paragraphs we will focus on the anticipation and evaluation of benefits on the subproject level, because those are afflicted with a lot more indefiniteness than the anticipation of the costs. Further the relevant figures had been estimated for each subproject individually. The data of the subprojects thus represent the direct foundation for the business case at program level.

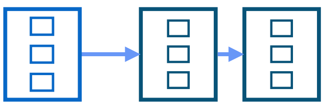
The elements considered within the business case are illustrated in Table 1.

Scope of the Business Case at Change Program level:

Cash Flows: ▪ Gross economic benefits (quantified measurements) ▪ Gross costs (costs for the realization of the Change Program and running costs for the new processes) ▪ Net cash flows (p.a. ongoing and accumulated)
Risks: ▪ Risks of economic benefits (in a generic and qualitative consideration)
Reference Parameters: ▪ Cost domains: design and development cost, verification and validation cost, ramp up cost, manufacturing cost, warrant charges, service cost ▪ Coverage: implementation in the considered product development projects ▪ Time horizon: from start of Change Program until end of considered product development projects

Table 1. Elements considered within business case at the beginning of the Change Program

A "rapid-evaluation-model" built on a generic description of subproject measures and their effects. Deducing detailed figures appeared as a very complicated process. Neither comparable experimental values from other projects nor reference values from literature were available for an orientation. In addition, there was a methodological guideline given by the program management, but not on a detailed level, which enabled a consolidated consideration of the overall benefits across all subprojects. The detailed estimation of the benefits thus was in the responsibility of the subproject leaders. In the following the approach proceeded by the subproject “Configuration Management” is discussed. [see Figure 3]

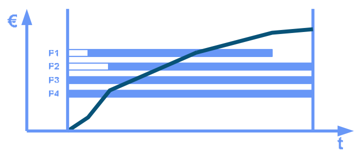


Step 1: analysis of measures and effects

- rough and general descriptions of measures and hypothesis of effects and quantifiable factors

Step 2: evaluations

- global evaluations by Project Management per cost domain
- analysis of determinability per cost domain
- focus on selected cost domains with high impact

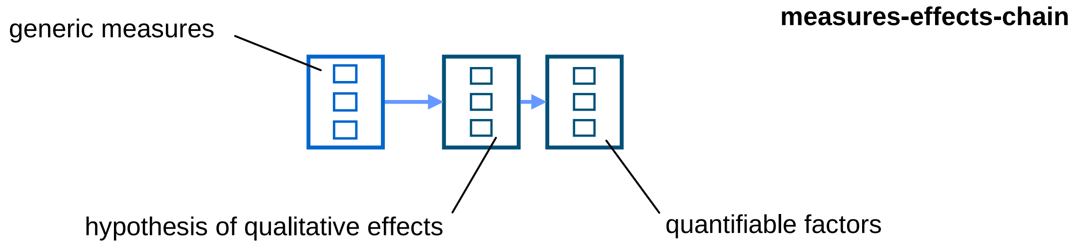


Step 2: calculation of results

- one scenario model based on selected cost domains
- approximate calculation of benefits over time and for product development projects

Figure 3. Overview of the business case methodology at the beginning of the Change Program

Step 1: The general description of potential measures by the subproject, hypotheses of their effects and their quantifiable factors. Purpose of this first step was to derive a qualitative model of subproject benefits. As mentioned before, the process measures to be taken by the subproject were indistinct at that point, thus only a rough and general description could be made. Therefore the hypothesis regarding the qualitative effects and their quantifiable factors were also only describable in a rough and general way. [see Figure 4]



Example (condensed):

Generic measure: implementation of a consistent and concerted Configuration Management Process
Hypothetical effect: development process is stabilized in early phase
Quantifiable factors: number of expensive changes in later development phase is reduced; overall development cost are reduced

Figure 4. General description of measures, hypotheses and quantifiable factors using configuration management as an example

Step 2: The concentration on cost domains within the development lifecycle with estimable and significant impact. As indefiniteness and difficulty evaluating measures and their impacts was a big issue, only those cost domains within the development lifecycle were chosen, in which the most significant impacts were expected and where a realistic estimation could be made. Therefore the impacts per cost domain were evaluated roughly as basis for the selection. Due to the focus of the Change Program the highest expected impacts aim at the following cost domains. [see Figure 5]

- design and development cost
- verification and validation cost
- warranty charges

Especially the warranty charges take an important place. As the amelioration effects are multiplied by the number of produced cars. This cost domain is the most important lever. However there are considerable uncertainties in the evaluation related to that cost domain, because the new processes only have direct impact during the product development phase. In all following lifecycle phases, new processes have indirect impacts by the higher product quality achieved during product development. So the further a cost domain is within in the lifecycle, the more difficult an accurate estimation is.

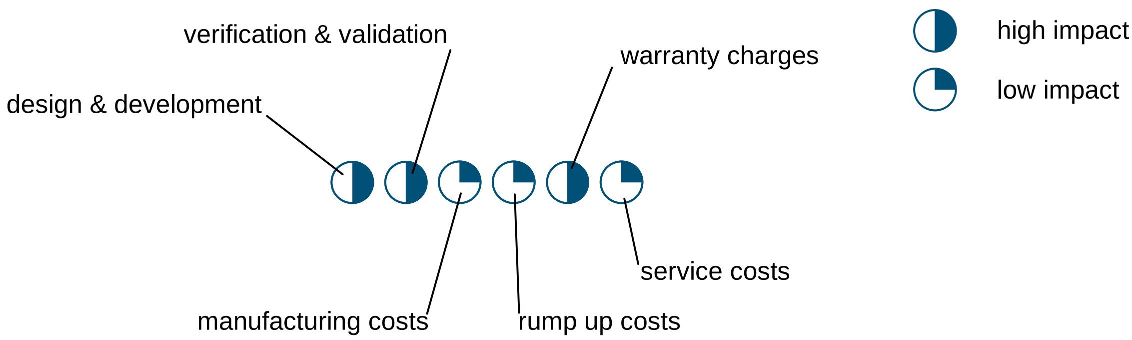


Figure 5. Strength of impacts on the cost domains within the development lifecycle (in their rough evaluation)

Step 3: The approximate calculation of the benefits. The calculation followed a consideration based on three questions:

- What is the share of electric/electronic development and verification budget respectively the share of warranty charges due to electric/ electronic failures that can be influenced?
- What is the proportion thereof that can be influenced by Configuration Management?
- What is the presumable impact of the measures in the given frame?

The underlying systematic thus was an estimation of influenceable proportions. In total, the reduction of warranty charges represented about 90%, the reduction of development/verification costs about 10% of the overall business case. As mentioned, the warranty charges need careful attention. Through the multiplication factor a small percentage of amelioration is enough to realize huge figures. An apparent little variation in the assumed percentages brings an enormous leap. 4% or 5% amelioration seem close, but in fact are equivalent to a difference of 25%. Both assumptions are credible and who can make assumption so precisely?

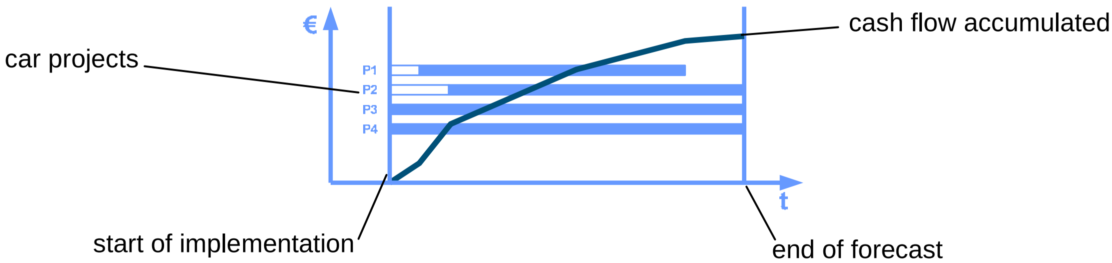


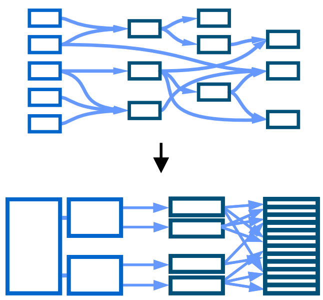
Figure 6. Economic benefits accumulated over time for different development projects (schematic view)

Validation of benefits – the business case at the end of the Change Program

The business case as basis for further planning. At the end of the Change Program the processes were developed, implemented or in stage of implementation. The costs of the projects and the costs for the execution of the new processes were well known at that time. However the proof of the anticipated benefits still had to be done. The purpose was to take a closer look on the measures and their effects that were already visible or that could certainly be expected. The information about the degree of achievement of the anticipated benefits was necessary due to the following reasons: The anticipated benefits had already been taken into account within the budget planning of current development projects - not achieving the anticipated benefits would have meant correcting their budget planning. Moreover realizing that the anticipated benefits would not be achieved would have left time for decision on continuative or correcting measures.

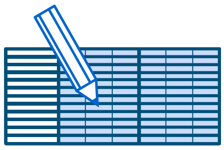
According to the organisation of the Change Program the view was again that of single subprojects who had to validate their initially stated benefits or to show up potential variations. The methodology thus was up to each subproject.

A scenario based validation-model built on a detailed analysis of measures and effects and the quantification by experts' estimations. The fundamental logic of the methodology from the business case at the beginning of the Change Program has been kept due to the objective of validation. The essential difference is that a more detailed analysis was made as a basis for experts' estimations including value ranges for building up scenarios.



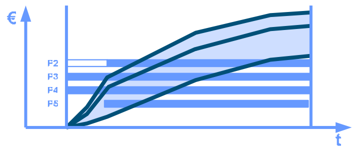
Step 1: analysis of measures and effects

- identification of the specific measures and their effects (step 1a)
- identification of the key-structure of measures and effects (step 1b)



Step 2: evaluations

- evaluations by experts

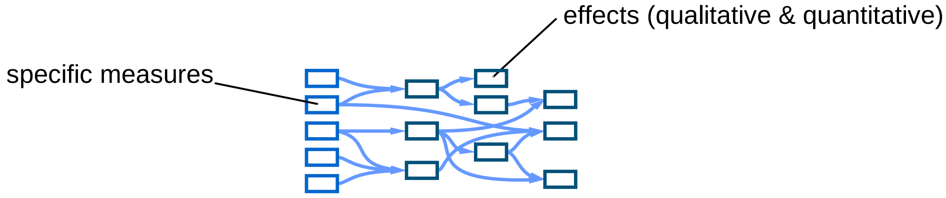


Step 2: calculation of results

- scenario creation (Monte Carlo Simulation)

Figure 7. Overview of the proceeding – the business case at the end of the change program

Step 1a: Identification of the detailed process measures and their effects. For this intention a workshop with the entire subproject team was held. First detailed process measures were collected in a brainstorming and subsequently classified in terms of building blocks of the Configuration Management approach at BMW Group. In the following effects were collected in another brainstorming and linked to the corresponding measures or precedent effects. The result was a network of qualitatively described measures and effects. Involving the entire subproject team enabled a complete view showing interdependencies. However the network of measures and effects was very complex and therefore hardly manageable for the next steps.

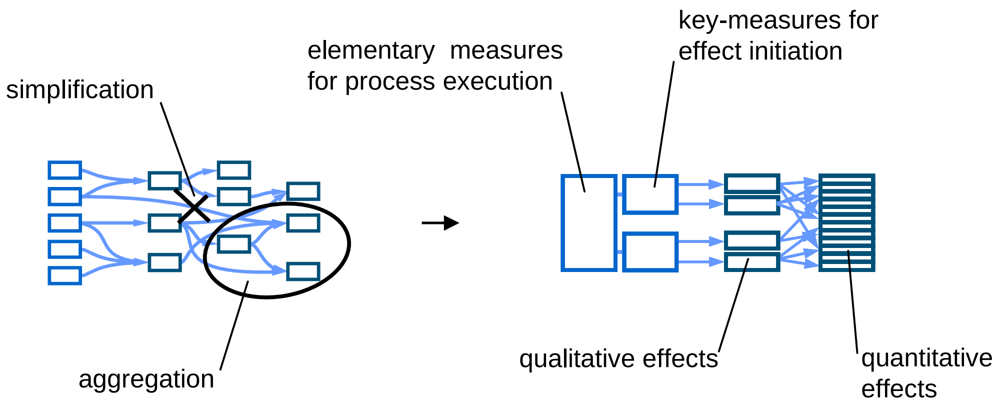


Example (condensed):

Measure: a change control board (CCB) is established
Effect: a higher quality of decisions
Consecutive effect: unexpected negative effects of changes are avoided; less redundant work

Figure 8. Detailed network of measures and their qualitative/ quantitative effects (schematic view)

Step 1b: Identification of super-structure of measures and effects. For an easier handling the complex structure developed in the precedent step was aggregated and simplified where negligible relations could be omitted. The measures were classified in elementary measures for the process execution and amelioration and key-measures for the effect initiation. The key-measures lead to qualitative effects that again lead to quantitative effects. In this structure the main measures-and-effects-chains were distinct, an important condition for the following work.



Example (condensed):

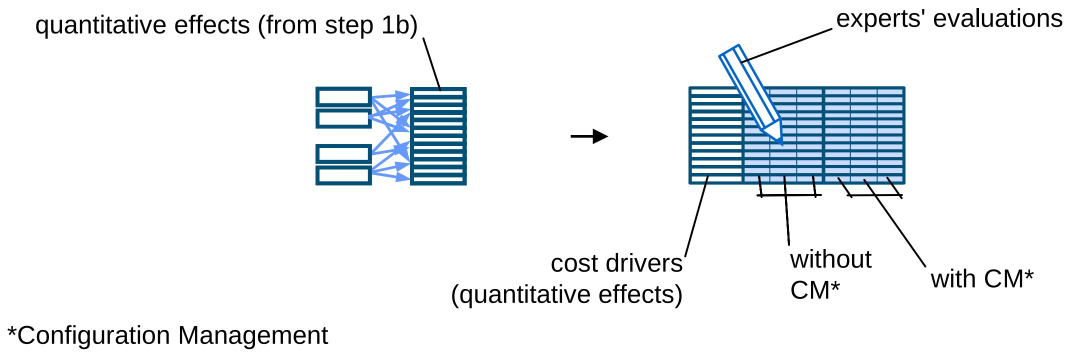
Basic measures for process execution: defined responsibilities, process methodologies, etc.
Key-measures for effect initiation: measures that lead to consistent electric/ electronic development status
Qualitative effect: all data of the electric/ electronic development status are checked in terms of validity, completeness and coherence
Quantitative effect: reduction of time for redundant work

Figure 9. Deduction of the super-structure of process measures and effects (schematic view)

Step 2: Data collection by interviewing experts. Data in the appropriate structure and in the level of detail corresponding to the quantitative effects was merely available. Thus the way chosen for data collection was to interview experts estimating the quantitative effects (cost drivers). The figures can be considered as validated because of four reasons:

- The experts were interviewed one by one so that a mutual influence was excluded (=neutrality of the statements).
- Several experts per quantitative effect were interviewed
- The experts evaluated measure-and-effects-chains they had experienced within development projects
- For each quantitative effect the experts estimated a range in which they expected the effects (= minimum value, maximum value, most probable value).

The selection of the experts followed the idea of complete coverage taking into account systems level and component level, different product lines and the different measure-and-effect-chains. During the interviews first the super-structure of measures and effects using an example for illustration was explained. Then the expert was asked to make his estimation for each effect. An astonishing experience during the interviews was the differences in qualities of statements. The ability and willingness to make estimations varied a lot from expert to expert. Obviously this was due to personality, education, experience, and position within the company. Also the status of the implementation of the measures played a decisive role. Only estimations about measures that were personally experienced by the expert could be made, estimations about measure not yet implemented were not possible.



Example (condensed):

Cost driver (quantitative effect): Loss of time because of errors/redundant work: [h/week]
Estimation without CM: best case: 1h | most probable case: 3h | worst case: 10h
Estimation with CM: best case: 0,5h | most probable case: 2h | worst case: 8h

Figure 10. Experts' evaluation per cost driver considering band widths of effects (schematic view)

Step 3: The forming of scenarios. The last key-element for validating the business case was the forming of scenarios. Scenarios in this context means taking into account different perspectives of the elements of the business case. The following elements had been considered (but for simplification/ better handling some had been neglected):

- magnitude of effects (cost drivers) in band width
- evolution over the given time period
- degree of implementation/realization

- dependencies from other processes
- effects on different product lines/development projects
- time period
- before tax/after tax, discounting

Particularly interesting in this case is the evaluation based on effect ranges. By those, inaccuracies and in this sense also the degree of implementation/realization as well as dependencies from other processes was included (the simplifications mentioned above). Using a Monte Carlo simulation a sensitivity analysis was provided. It shows the most probable total value at a given time combining all values of the single quantitative effect (cost driver) respecting their probability (described by minimum value, most probable value and maximum value). By that the evolution of the benefits over the given time period could be evaluated, respecting the fuzziness implied in the complexity of the evaluation model.

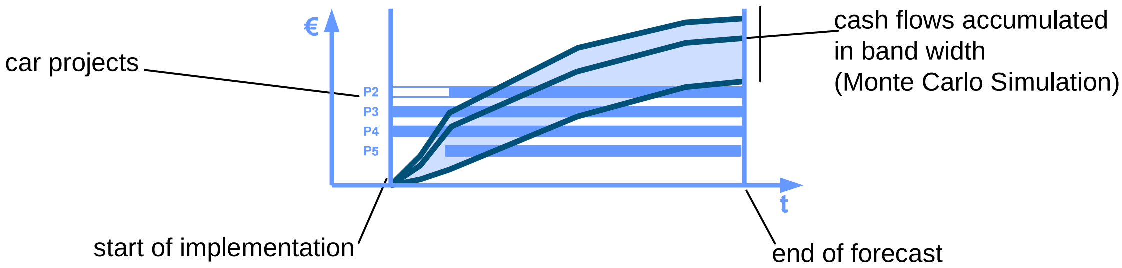


Figure 11. Example of scenarios of benefits accumulated (schematic view)

Example illustrating the application of the business case methodology

In this section the application of the business case approach at the end of the change program is highlighted using a consistent example from BMW Group with neutralized data. An application at the beginning of the change program is not discussed, since it is less interesting and complicated. As shown in figure 7, the methodology consists of three steps:

1. Analysis of measures and effects
2. Evaluation by experts
3. Calculation of results

Within the first step measures are identified and their effects in terms of qualitative and quantitative factors are analyzed. Within the subproject Configuration Management several measures were introduced into the electric/electronic development process. One was the introduction of a baseline management process, consisting of a baseline planning phase, a baseline preparation phase, a baseline review phase, and a baseline release phase. Introducing this process was a basic measure, which effect in total is hard to evaluate. By taking out process phases in a first step **qualitative effects** could be identified. E.g. the baseline review phase led to a higher completeness, validity, and consistency of the baselines released within the development process. These effects are still not quantifiable in overall. Now **quantitative effects** could be identified. E.g. by increasing the quality of the baselines released, the number of defects within components ordered for prototypes on the basis of these baselines could be reduced, which led to a reduction of cost due to bug fixes or even new components to be ordered to substitute the old.

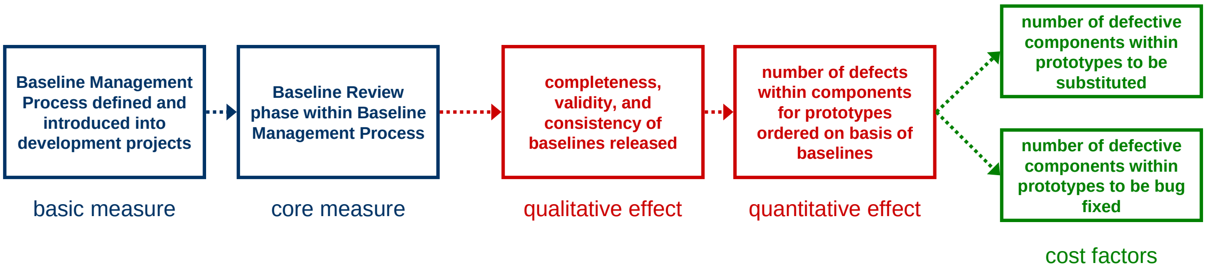


Figure 12. Measure-effect chain using baseline management process within configuration management as an example

On basis of such measures-effects chains experts within the electric/electronic development process are able to assess figures for quantitative effects. By asking experts not for absolute figures but for **relative figures within some range** (e.g. minimum, maximum, and likely values for reduction in %) and by asking a number of experts independently, a data basis is build which allows for calculation. In the above mentioned example of baseline reviews, experts were able to assess a typical number of components per review phase which were defective due to low baseline quality, and a reduction of defective components due to the new process. Experts also were able to assess the typical share of components to be substituted by new ones and the share of components to be bug fixed. Supplementing these expert data by basis data like typical cost per component, typical cost per bug fix, typical number of prototypes per review phase, number of review phases per year, number of development projects in which process is introduced, is a calculation for a measure-effect chain is possible (see fig. 13).

	assessment by experts				basis data				
	% reduction								
cost factor	min. value	likely value	max. value	current number per prototype	typical cost per defective component	typical cost per bug fix	number of prototypes per review phase	number of review phases per year	number of projects
number of defective components within prototypes to be substituted	10 %	20 %	30 %	10	1000,00 EUR	300,00 EUR	40	2	2
number of defective components within prototypes to be bug fixed	20 %	30 %	50 %	20					

calculated value range

352.000,00 EUR *(minimum value per year)*
608.000,00 EUR *(likely value per year)*
960.000,00 EUR *(maximum value per year)*

Figure 13. Calculation of business case for measure-effect chain using baseline management process within configuration management as an example (note that the data is neutralized)

Lessons Learned and Success Factors

A business case is an instrument used with a specific purpose. It provides the basis for deciding about the realization of projects and about the distribution of budgets. Independently from the project stage when a business case is made, the way to credible figures is a complicated one. Structure, choice of measurements and mode of data collection are crucial. In the following the most important lessons learned from setting up the business case for the Change Program at BMW are illustrated and success factors are derived.

Structure of Business Case. In the case of a bigger and complex program that is divided into subprojects, there are two possibilities of perspectives on the benefits. On the one hand the program may be regarded as an entity. In this way the interdependencies of subprojects will be taken into account, but in the concretization of the benefits one will have to deal with a complex structure of relevant aspects. On the other hand each subproject may be analyzed separately. The specific problem one will have here is the aggregation of subproject benefits. In the simplification of aggregation interdependencies and multiple appearances of benefits between the different subprojects are neglected or at least difficult to be taken into account.

In order to achieve transparency and credibility of a business case it is important to have a traceable proceeding. Especially if a program is divided into subprojects comparability is key to overall integrability and thus credibility. An obliging guideline for the subproject managers is very helpful.

Concerning the structure of the business case one should also think about its purpose. A business case can be more than a 'political instrument'. In addition it can be an instrument that supports the effective development of new processes. It is just like making a diet. The wish is to loose weight. First the person thinks about how to weigh itself – in the morning or in the evening/ with or without clothes (= definition of the measurements). With that person has the initial value to which the desired target value is related. The following diet program will be arranged and aligned according the measured progress. The person has always clearly in mind what factor has to be affected.

Choice of Measurements. The derivation of the relevant measurements can only be done by putting up the measures-and-effects-chain. To get a correct list of measurements the degree of measures and qualitative effects is not the essential point. Important is to get a clear picture of the fundamental structure. For a valid result the project team should be integrated for elaboration, but one has to think deeply about that step to be able steering the output. The operative process users should also validate the final measurement list. A success factor for the later data collection is to choose comprehensible measurements that are demonstrative by their wording and the use of examples.

One problem should be treated very carefully in the analysis of the measures-and-effects-chain. It is the problem of the temporal distance of measures and effects. If you have for example measures at the early lifecycle stages and effects in a later lifecycle phase (e.g. warranty charges) it is difficult to distinctly relate the effects to the corresponding measures. The impacts are realized in an indirect way and a contribution of other projects cannot be clearly separated.

Mode of Data Collection. Experts are often the only way to get the needed data. Their consultation is therefore a good method to achieve a credible and validated business case, because of their neutrality due to the fact that they are working in the operative environment. It is extremely crucial to make the right selection of who you interrogate. Estimations from ‘gurus’ have a lot more weight than an apparently more representative, bigger group of 'normal experts'.

However interrogating experts is a difficult matter. Mostly they can only estimate what already shows its complete effects – even if they are experts who know very well old and new processes and who have larger overview. Estimations of upcoming effects are barely possible. Astonishingly already the evaluation of an actual state is difficult to do. To facilitate the interrogation three aspects should help. Interrogations by thematic groups are faster to execute than individual interrogations. The super-structure of measures and effects that lead to the measurements has to be conveyed as clear as possible. The estimation of the initial values (before the new processes) and the estimation of the new values (after the introduction of the new processes) might be separated. Moreover structured evaluations schemes are helpful for the experts to make their statements.

Summary and Conclusion

This paper aimed at illustrating a methodology for evaluating the benefits of introducing new development processes. The methodology illustrated was developed and applied during a Change Program within the electric/ electronic development at BMW Group. The paper was meant to contribute to the discussion on the value of Systems Engineering processes.

Evaluating the value or benefit of System Engineering processes is a difficult thing to do. Ether you have to deal with indefiniteness or you have to analyze a complex structure of interdependencies and indirect impacts. Especially the evaluations of avoided costs that are achieved indirectly through a cascade of effects are critical.

The principles of the methodological approach at BMW Group at the beginning and at the end of the Change Program were analog. The difference laid in the level of detail and the integration of value ranges to cope with inaccuracies. The first approach should make a statement about the anticipated benefits; the second had to make a statement about if the anticipated benefits would be achieved. The methodology was to make three steps. In a first step the measures-and-effects-chain (qualitatively and quantitatively) had been identified. The second step concerned the data collection either by a global estimation or an estimation of changes of single cost drivers that were finally summed up. The estimation was done by the project management or by the interrogation of experts. As third and last step one or several scenarios were built up to give a picture of the anticipated or measured benefits.

The approach chosen was the result of a search for a pragmatic approach and was developed in an ongoing manner. Its basic structure and in the following taken decisions had always determining effects for the following steps. Setting up credible business cases for Systems Engineering processes needs for methodological and research work, steady improvement based on lessons learned, and an intense discussion within the SE community.

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Biography

Erwin Knippel received a Diploma Degree in Electrical Engineering focussing on communication networks from Fachhochschule Rheinland Pfalz in Trier in 1988. He started his professional career at BMW as SW/HW engineer for ECUs within chassis development. In 1995 he switched to BMW M GmbH, a BMW subsidiary for sport cars and worked there as CA system administrator. In 1998 he switched to BMW Technik GmbH, another BMW subsidiary for study cars and became head of IT infrastructure as well as project leader for PDM introduction. In 2002 he moved back to BMW and took over as project leader configuration and change management within electrics/electronics development.

Armin Schulz received a Diploma Degree in Aerospace Engineering from Technische Universität München (TUM) in 1998 after studying at TUM und Massachusetts Institute of Technology (MIT). In 2002 he received a Ph.D. in Systems Engineering from Technische Universität München after completing his research on „Information Architectures within Product Development“. From 1998 until 2002 he worked with several industrial partners from automotive and aerospace industry on issues of information management and concurrent engineering environments. In 1997 he was co-founder of the German Chapter of INCOSE and has been member of its board from 2000 until 2003. In 2001 he became co-founder of 3D Systems Engineering (3DSE), a consulting firm in the area of Systems Engineering, and has been working with 3DSE since then.