Professional MBA
Automotive Industry

Development of a Method to Determine Productivity in Engineering Services for Creating Lean Offers

A Master's Thesis submitted for the degree of
"Master of Business Administration"

supervised by

Univ.Prof. Dr.-Ing. Dipl. Wirtsch.-Ing. Wilfried Sihn

Naresh Laddha

1525955

Vienna, 25.09.2017

Affidavit

I, **NARESH LADDHA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "DEVELOPMENT OF A METHOD TO DETERMINE PRODUCTIVITY IN ENGINEERING SERVICES FOR CREATING LEAN OFFERS", 71 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 25.09.2017

Signature

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This thesis is dedicated to my mother who set in me the desire to learn, irrespective of the age and circumstances.

Abstract

"*The single great challenge... in developed countries of the world is to raise the productivity of knowledge .... This challenge will ultimately determine the competitive performance of companies … and the quality of life in every industrialized nation*" (Drucker, 1991, p. 94).

The automotive industry is in a fast transition towards clean energy driven powertrains and digitalization. To win the outsourced opportunities from the 'Original Equipment Manufacturers' (OEMs), apart from technical competences, 'leanness of the offers' is the key for the 'Engineering Service Providers' (ESPs). From the well-established principles of lean, this means: 'deliver customer-defined value by reducing waste**'.**

The measurement of productivity is an important element in the assessment of leanness. The common methods of productivity measurements in the manufacturing sector cannot be applied in the engineering services, due to the highly intangible contents of both output and input.

This research: (1) Identifies and analyses the parameters, which constitute the inputs & outputs of an automotive ESP and establishes quantifiable 'Key Performance Indicators' (KPIs) of these parameters; (2) Develops a method to analyze an offer for its productiveness; (3) Recommends a framework of proposals to achieve lean offers.

The method developed for the productivity measurement was tested using offers of an ESP. The results demonstrate the suitability of the method and its capability in highlighting the areas of improvement in an offer, to make it lean.

Keywords:

Automotive, Productivity, Engineering service, Lean

Table of contents

List of abbreviations

Abbreviation	Acronym
BDP	Battery Development Process
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CE	Chief Engineers
CFD	Computational Fluid Dynamics
COP	Carry Over Parts
CVCI	Customer Value Creation International
DEA	Data Envelopment Analysis
DVP&R	Design Verification Plan and Report
EDP	Engine Development Process
EPMS	Engineering Productivity Measurement System
EPO	European Patent Office
ESP	Engineering Service Provider
FMEA	Failure Mode and Effect Analysis
HiL	Hardware in Loop
IFC	Issued for Construction
KLEMS	Capital, Labor, Energy, Materials and Services
KPI	Key Performance Indicator
LE	Lead Engineers
MAR	Marshal-Arrow-Romer
MFP	Multi-factor Productivity
MiL	Model in Loop
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PCP	Product Creation Process
PDP	Powertrain Development Process
PVR	Project Variation Requests
QCWF	Quality, Cost, Weight & Functionality
SFA	Stochastic Frontier Analysis
SFP	Single-factor Productivity
SiL	Software in Loop
TDP	Transmission Development Process
TPS	Toyota Production System
TTM	Time to Market
USP	Unique Selling Proposition
USPS	Unique Selling Proposition Specification
VSM	Value Stream Mapping
V&V	Verification and Validation
XiL	Term used for combination of virtual environments

1. Introduction

Since the invention of an automobile in year 1886 and its industrialization from year 1909, the automotive industry has made a remarkable impact on the lives of people every day.

In the European Union, the automotive industry contributes to 6.5% of the GDP and provides employment to 5.6% of the total workforce. Apart from the economic figures, the importance of this thesis topic is underlined by the fact, that the automotive sector is the largest private investor in R&D in Europe, with an investment of ~ Euro 45 Billion. About 6000 patents were granted by the European Patent Office (EPO) in 2015. (ACEA, 2016)

These figures indicate the innovative nature of the European automotive industry. After the revolutions in the production systems till 1990, the product innovation period started. *Especially in the last one and a half decades, the product range and its variants grew exponentially, theoretically reaching to* 10^{32} (Palm, 2016, S. 72).

The industry developed various methods and processes like the ‘Toyota Production System’ (TPS) and ‘Modular Assembly’, to cope with the production and logistics of these variants. However the pressure on product engineering and development is also equal if not more. The challenge is to develop so many variants with high reliability and bring them to market within time. Additionally all this must be met keeping in view the most important factor of product cost.

Lately two major driving forces have made this challenge more complex. These are:

a) The legislative requirements to meet the stringent emission norms → this is driving the subsystem level complexity and development efforts of the powertrain.

b) Digitalization → this has added a lot of additional efforts in the development process in form of infotainment and connectivity, including its hardware and software development.

To meet these challenges of product innovation and development, the engineering departments of the automotive ‘Original Equipment Manufacturers’ (OEMs) have been cooperating with and outsourcing many of their tasks to companies specialized in this field. We call them ‘Engineering Service Providers’ (ESPs).

This thesis aims to deal with the challenges faced by the ESPs in winning such opportunities outsourced by the OEMs.

1.1. Problem statement

There are two main challenges for an ESP, which can be ranked at the outset as:

> **Priority 1: Winning the Opportunity**. Apart from the prerequisite of being technically competent, the competitiveness or leanness of the offer is decisive. Due to the uniqueness of every opportunity and the value added output in automotive engineering services, the economies of scale or volume benefits, as available in production sector, cannot be applied to make the engineering offers competitive.
>
> **Priority 2: Profitability**. For the basics of any business, profitability is crucial for its long term stability. Profit, which is money available after all the expenses, allows reinvestment in R&D to further improve the technical competences. This means that in long run, the profitability facilitates the pre-requisite of winning opportunities.

This interlinking of the above two challenges, indicate a commonality in solution. That is: **to become highly productive.**

Therein, the question arises: What is productivity in automotive engineering services and how can it be measured?

Since many years, efforts are made by different service sectors including engineering, to establish analytical methods for measuring productivity. However, due to the involvement of specific intangible factors, no method applicable for automotive services is available.

The main questions, which need formidable answers to develop a productivity measurement method are:

i) What are the parameters that define the output of an ESP and how does the customer (i.e. an OEM) assess it?

ii) What are the inputs used by the ESP for achieving the output?

iii) What are the Key Performance Indicators (KPIs) of these output and input parameters, which can make them objectively quantifiable for measuring the productivity?

1.2. Research objectives

The primary objective of this research is to develop a method for determining productivity right from the offer phase, in order to achieve lean offers.

More specifically, the objectives are further focused on:

1) Identifying and analyzing the parameters, which constitute the inputs & outputs of an ESP and establishing the KPIs of these parameters, to make them quantifiable.
2) Establishing a method to analyze an offer for its productiveness.
3) Recommending a framework of proposals, to achieve lean offers.

1.3. Research scope

As the focus of this thesis is on the development of a method for productivity measurement of an automotive ESP, the company AVL List GmbH (AVL) is taken as reference.

AVL is *the world's largest independent company for the development of powertrain systems with internal combustion engines as well as instrumentation and test systems. AVL Powertrain Engineering is an expert partner to the global automotive and mobility industry for the development of innovative powertrain systems. From diesel engines to electric drives, from alternative fuels to control software, from transmissions to batteries, (…).* (AVL List GmbH, 2017)

For the data generation and validation, the offers based on AVL’s Engine Development Process (EDP) are taken as basis. This is because, the EDP represents many development processes in automotive powertrain and powertrain elements. The sub processes like design, simulation, validation etc., which are generally outsourced by the OEMs are included in the EDP.

The method of productivity measurement can be applied in any context of automotive service.

However following services/ business models are excluded from this research:

- Manpower leasing

- Services based on individual tasks where a development process is not involved. E.g. a single simulation or testing task for a component

1.4. Background of key terms

In order to keep the focus on the topic, this section clarifies the definitions of some of the important words relevant to the topic.

1.4.1. Productivity

Productivity is "*A measure of the efficiency of a person, machine, factory, system, etc., in converting inputs into useful outputs. Productivity is computed by dividing average output per period by the total costs incurred or resources (capital, energy, material, personnel) consumed in that period. Productivity is a critical determinant of cost efficiency."* (Business Dictionary, 2017)

In this definition the word efficiency is used. At this instance it is important to clarify the difference between productivity and efficiency.

"Being productive means you are successful in producing a …intended result. Matching your efforts with the work that requires your unique skill set …More engaging, more difficult … but infinitely more rewarding. Being efficient means you are working in a well-organized and competent way." (Feldman Danzger, 2016)

In his unpublished paper about engineering productivity, Tom Gilb says, "*An engineer is productive to the degree they contribute to an engineering effort that is successful in delivering promised requirements, to real stakeholders, in a timely manner (at or before agreed deadlines). An engineer is more efficient if they can reduce the resources needed to deliver requirements on time to stakeholders."* (Gilb, 2008)

The above definitions and interpretations indicate the utmost need for an ESP to be OEM focused and provide highly productive services. → To win the opportunities by means of lean offers.

At the same time, the engineers at an ESP need to work efficiently. → To improve the profitability by delivering the defined output with minimum efforts.

1.4.2. Lean

This research aims to develop a method for achieving a '**lean**' offer in order to win the opportunities provided by the OEM as explained in section 1.1.

However, the word lean should not be misinterpreted as minimum. In the automotive manufacturing world, the principle of lean is well established and it means to 'provide **customer-defined value** by **reducing waste'**.

"We can see and feel the waste of material things. But our larger wastes of human effort, which go on every day through such of our acts as are blundering, ill-directed or inefficient […], are less visible, less tangible and are but vaguely appreciated." (Taylor, 1911)

In the context of engineering services, this waste of human efforts, not adding value for the customer, needs to be minimized.

1.4.3. ESP

Since 1980s, the architecture of automotive industry transformed deeply. Depending on the OEM and type of vehicle, between 70 to 80% of value creation involves suppliers. In Figure 1, the architecture of automotive value chain is shown as a truncated pyramid. The suppliers, generally termed as Tier 1, Tier 2 & Tier 3 respectively from top, depending on their contracting arrangements are the layers of this pyramid. (Frigant, 2011).

However, an ESP is involved at the upstream of the value chain as shown in the upper right corner of Figure 1. Due to its upstream involvement with the OEM, the ESP plays an important role in the product development and becomes a key player in regard to the market success of the product.

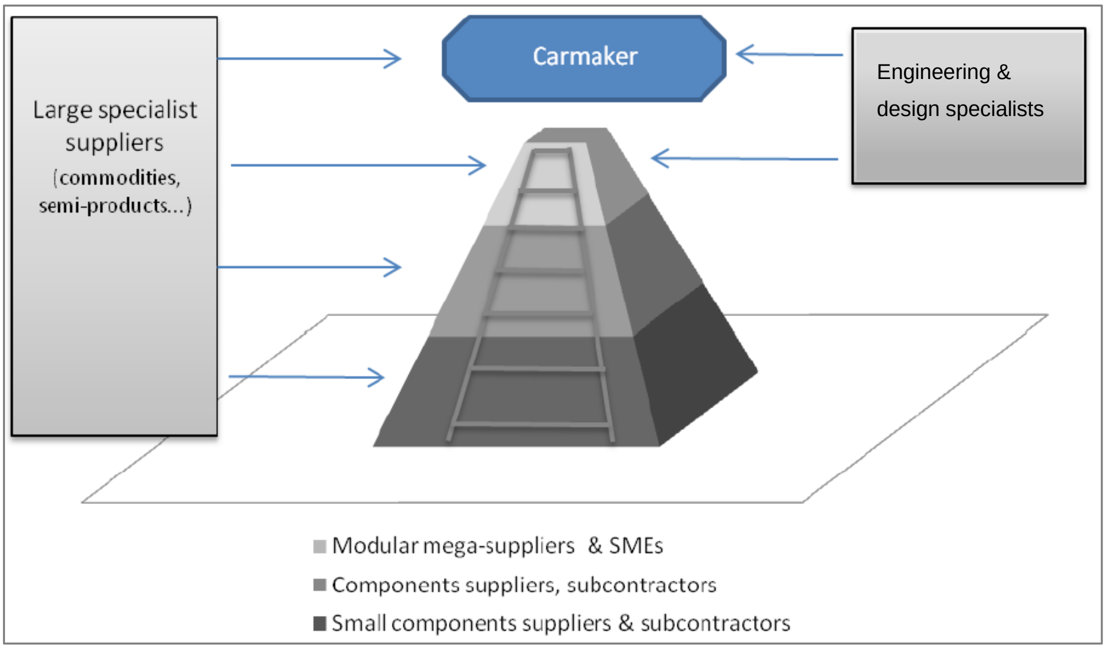


Figure 1. ESP role in the automotive industrial architecture: an Aztec Pyramid

1.4.4. ESP’s scope

Figure 2 below, shows the envelope of Product Creation Process (PCP) of an OEM, which includes both development and productionizing. As shown in the blue colored area, an ESP contributes to a part of the PCP.

For its part of work the ESP has to use its own inputs, as well as inputs received from the OEM and convert them to the defined output at a defined time point of time (shown as orange colored milestone).

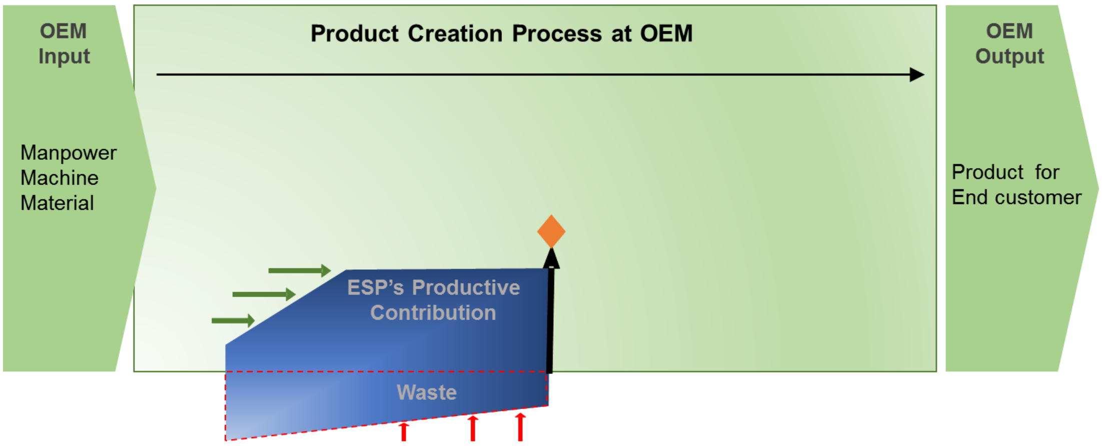


Figure 2: ESPs contribution in PCP

Assuming that the ESP is 100% productive, the blue area will lie completely in the green rectangle of OEM's PCP. However, this ideal state can never be reached due to many factors, which are explained later in this thesis.

Thus, the area marked by the red dotted line represents the non-productive part of the ESP. The aim of achieving a lean offer would therefore mean reducing the size of the red dotted area, which does not add value to the OEMs product creation process.

1.5. Structure of the thesis

This thesis is structured in 7 Chapters.

The academic background is covered mainly in Chapter 1 & 2.

Chapter 1 'Introduction' covers the problem statement, research objectives, research scope and information of key terms used during the research.

Chapter 2 details the 'Literature review' by looking at the state-of-the-art methods and previous research done on similar topics in different industries.

In chapter 3, the Goals and requirements of the method for measuring productivity are defined.

Chapter 4 details the work for 'Development of method'. This consists of scientific preparation and data generation work in industrial context. The productivity parameters, their KPIs and the mathematical functions in arriving to the final productivity metrics are explained.

In chapter 5, the 'Data analysis and discussion of findings' from the executive interviews and productivity calculations are performed.

Chapter 6 'Method validation and implementation' covers the validation performed for the methodology, the implementation process and the proposals for achieving lean offers.

Chapter 7 '

Conclusion and recommendations' summarizes the research in terms of achieved goals and its contribution. Finally the recommendations for further research are outlined.

2. Literature review

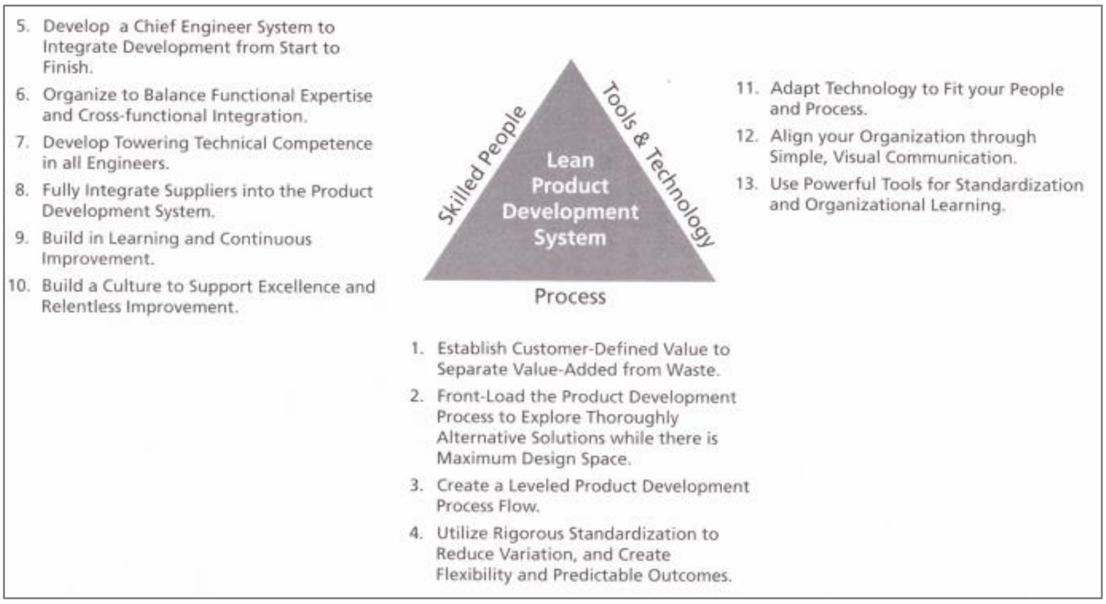
2.1. State of the art

Lean production, based on the ‘Toyota Way’ or Toyota Production System (TPS) has been spread and practiced in manufacturing sector across a wide range of products. *Companies like Nike, Kimberley-Clark, and Intel are amongst the lean manufacturers. From the automotive sector, Caterpillar, John Deere, Ford and Toyota are amongst the lean manufacturers* (STAFF WRITER, 2014). Toyota being the leader and founder of lean philosophy, has set many milestones in the field of lean production, on which many books and journals are published. The most knowledge enhancing book in this field being ‘The machine that changed the world’.

This research however focuses on ‘lean product development’. Also here, a lot has been done by Toyota. This profound knowledge and over twenty years of research work is explained in the book ‘The Toyota Product Development System’ by James Morgan and Jeffrey Liker.

In his foreword for this book, James P. Womack, one of the authors of ‘The machine that changed the world’ and Chairman of Lean Enterprise Institute says *“The Toyota system developed products in much less time with many fewer hours of engineering, products that cost much less to manufacture and that had many fewer defects as reported by customers. (…) This product development system consistently created more value with less time and effort, the very definition of lean.”* (Morgan & Liker, 2006, p. 15)

The book explains 13 principles of Lean Product Development System (LPDS), framed in three broad categories: Process, People and Tools & Technology. These principles are evolved and lived at Toyota, to meet new challenges and technologies. These principles are still state-of-the-art in many ways for various topics related to LPDS. (Morgan & Liker, 2006)



5. Develop a Chief Engineer System to Integrate Development from Start to Finish.
6. Organize to Balance Functional Expertise and Cross-functional Integration.
7. Develop Towering Technical Competence in all Engineers.
8. Fully Integrate Suppliers into the Product Development System.
9. Build in Learning and Continuous Improvement.
10. Build a Culture to Support Excellence and Relentless Improvement.

11. Adapt Technology to Fit your People and Process.
12. Align your Organization through Simple, Visual Communication.
13. Use Powerful Tools for Standardization and Organizational Learning.

1. Establish Customer-Defined Value to Separate Value-Added from Waste.
2. Front-Load the Product Development Process to Explore Thoroughly Alternative Solutions while there is Maximum Design Space.
3. Create a Leveled Product Development Process Flow.
4. Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes.

Figure 3: Lean PPD Model & 13 Principles (Liker, 2004, p. 176)

This research focuses on productivity as mentioned earlier. As this topic is covered mainly in the category of Process, following sub points explain the state of the art in process relevant area. The topic of People and Tools & Technology are skipped.

2.1.1. Establishing customer-defined value

This is the core topic, whose necessity needs to be understood by everyone at the ESP's organization for achieving the goal of lean offers and lean operation. If the OEM could not see value, in what he receives from an ESP, it is a waste produced by the ESP. Thereby defeating the whole purpose of business.

"The question 'What is our business?' can, therefore, be answered only by looking at the business from the outside, from the point of view of customer and market. All the customer is interested in is, his own values, his own wants, and his own reality. For this reason alone, any serious attempt to state 'what our business is' must start with the customer, and her realities, situation, behavior, expectations, and values." (Drucker, 2008, p. 101)

Many companies already use different methods to bring common understanding amongst each and every member of their organization regarding their customers' value. Similarly various professionals and nonprofit organizations e.g. CVCI (Customer Value Creation International) are developing innovative methods in this field.

2.1.2. Front-loading in product development

It is a well-established fact that in a development process, the constraints to make any changes increase significantly over the time. Changes at later stage mean repetition of work, which is nothing else but waste.

Front-loading in a development process is established in the industry using various combinations of methods. These are:

- Product portfolio, technology and platform management
- Evaluation of multiple design alternatives using low fidelity simulation models and rapid prototyping
- Decision making based on elimination method instead of quickly selecting a winner
- Use of virtual environments to check the interaction between hardware and software in early phase. MiL (Model in Loop) + SiL (Software in Loop) + HiL (Hardware in Loop) = XiL (term used for combination of virtual environments)

Looking from the stand-alone perspective of an ESP, front-loading may be the contrary to lean offer, however in the PCP of an OEM this can avoid a lot of loops. Thus, jointly agreed front-loading solutions add value to the final output of the OEM.

2.1.3. Levelled product development process

Due to the uniqueness of every project, the product development is not identical to product manufacturing. Looking at the product development as a ‘Process’, is therefore considered as the starting point for lean product development. (Morgan & Liker, 2006, p. 70)

Usage of Value Steam Mapping (VSM) in product development is slowly, however steadily growing. Many tools to enhance the product data management, project milestone and resource monitoring, etc. are used by the OEMs and ESPs.

However, there is yet a lot to happen to link individual tasks and improvement in a process that is transparent enough to identify the wastes.

2.1.4. Standardization

Nowadays, standardization amongst products (design/ architecture), processes (simulation sequences/ test procedures) and skills (experts like design/ validation/ measurement), is an established reality in automotive business.

Since the internet connectivity across the globe became strong and reliable, more and more startups have taken up the role of ESPs for special skills. For example:

- Design offices for CAD modelling
- CAE specialist who perform strength, multibody or CFD simulations
- Universities providing materials know-how

These ESPs are very efficient in standardizing the workflow in such areas. This is due to the experience in regular use of the tools mentioned above and the high utilization of these tools.

However, to make use of these standardized workflows, the product and application related requirements of an OEM need to be well understood by the ESP. The integration of these workflows into the development process of the OEM also becomes complex.

2.2. Productivity measurement efforts

Several literatures and publications were reviewed to understand the studies performed for measuring productivity. The review revealed that for the automotive industry near to nothing is available. Nonetheless, some very informative and relevant methodological research papers are available, which are explained below.

2.2.1. Measuring Productivity – OECD Manual

(OECD, 2001)

The Organization for Economic Co-operation and Development (OECD) published this comprehensive guide, covering various productivity measures used in multiple industries. It sets the theoretical foundations for measuring productivity and its implementation issues.

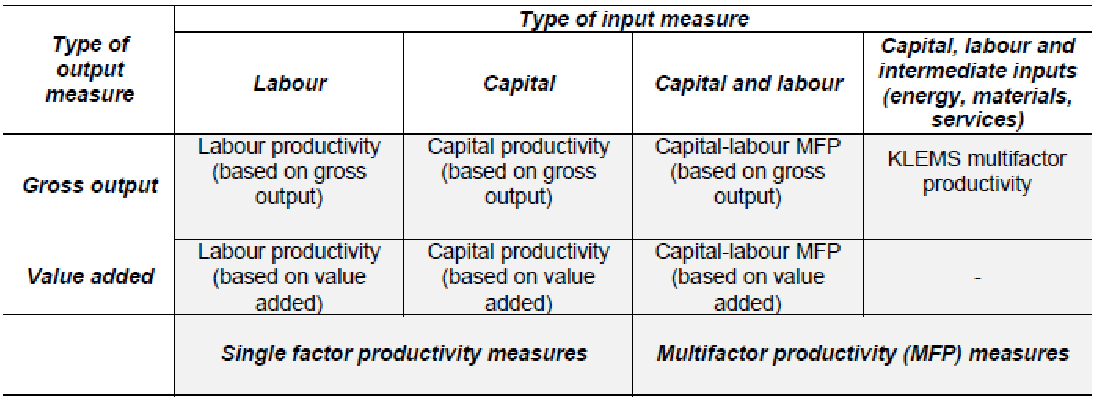
The manual provides an accessible guide to productivity measurement for statistical offices, relevant government agencies and productivity researchers. Through its indicative properties (no prescriptive guideline) of productivity, it can be used to improve international harmonization. It identifies desirable characteristics of productivity measures that links economic theory and index number theory. (OECD, 2001, p. 7)

The manual extensively explains following:

- Different types of productivity measures
- Outputs (gross as well as those based on value addition)
- Inputs (labor and capital)
- Index numbers (to aggregate the heterogeneous nature of goods & services)
- Aggregation of productivity growth across the industry
- Implementation guide

Globally, due to the various applications, the productivity measurement is categorized depending on its objectives. These categories are: technology, efficiency, real cost savings, benchmarking of production process and living standards.

Furthermore, the manual allocates various productivity measures depending on the type of output measure and the type of input measure.



Type of output measure	***Type of input measure***			
	Labour	***Capital***	***Capital and labour***	***Capital, labour and intermediate inputs (energy, materials, services)***
Gross output	Labour productivity (based on gross output)	Capital productivity (based on gross output)	Capital-labour MFP (based on gross output)	KLEMS multifactor productivity
Value added	Labour productivity (based on value added)	Capital productivity (based on value added)	Capital-labour MFP (based on value added)	-
	Single factor productivity measures		***Multifactor productivity (MFP) measures***	

Table 1: Overview of main productivity measures (OECD, 2001, p. 13)

For the data analysis, OECD used a 'non-parametric method[1]'. The choice of this method was made keeping in view the main audience, which are statistical offices.

Note: Non-parametric is a standard term used in statistical data analysis. It is not a property of any data. In this research, the term 'parameter' is frequently used in a completely different context.

The assessment of this literature is concluded in section 2.3.

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[1] Non-parametric method is a data analysis method. Unlike the parametric method, it does not require the data to follow any distribution or uniform variance. It also works with ranking of observations apart from the measurements themselves. The disadvantage is that it needs larger sample size.

2.2.2. Measuring the productivity of professional services

(Nachum, 1999)

While appreciating the intangible factors involved in the professional sector, the author discussed the difficulties in using them as parameters and proposed some measures to cover this topic adequately. The uniqueness of the service industry was validated by the example of Swedish management consulting companies.

The method suggested by the author is acknowledged by herself as inadequate for providing an operational control tool for the management, although it objectively compares the flaws of using manufacturing based measurement tools.

"Unless we improve the measurement of productivity (…), both in terms of the conceptual frameworks and the actual data needed for measurement, we will not be able to guide both firms and policy makers in this respect." (Nachum, 1999, p. 29)

Mrs. Nachum looked at the productivity in completeness i.e. considering the perspective of the end customer. For this purpose the input as well as the output parameters for measuring productivity were defined by combining the service provider and the client.

For the data analysis, a non-parametrical method called 'Data Envelopment Analysis (DEA[2])' was used. The usage of this method makes it possible to compare the relative efficiency of different companies in a group.

The assessment of this literature in concluded in section 2.3

2.2.3. EPMS for benchmarking

The dissertation 'Development and Implementation of an Engineering Productivity Measurement System (EPMS) for Benchmarking' (Kim, 2007) was performed for the construction industry.

Apart from definition of productivity metrics for the construction industry, an implementation method was also investigated.

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[2] DEA is a non-parametric data analysis method, which is frequently used in the field of science. The applications are for e.g. supporting decision making in R&D, performance measurement in non-profit organizations, etc. (Data Envelopment Analysis(DEA) - Ein Verfahren der Effizienzmessung)

The major hypothesis used in this research was, that the engineering work hours and design quantities represent the productivity. The design quantities are final designs that are ‘Issued for Construction’ (IFC).

In contrast to the common definition of productivity i.e. output divided by input, the construction industry defines productivity as Input divided by Output.

$$\text{Productivity} = \frac{\text{Actual Work Hours}}{\text{IFC Quantity Designed}}$$

This is basically a production rate (the lower the better). The IFC were collected from six main work categories and their sub areas. The rework was also considered in the total work hours to represent the reality.

The data collected from the industry and suppliers were represented through box-and-whisker plots. To determine whether a linear relationship exists between the work hours and IFC quantities, correlation analysis was used.

The author concluded that by using his *“research method of defining the engineering productivity using IFC quantities is valid and can provide meaningful data with common definitions (…) provides an effective benchmarking tool for the construction industry to measure engineering productivity”* in construction industry. (Kim, 2007, p. 137)

The assessment of this literature is concluded in section 2.3

2.3. Conclusion of literature review

From many literatures, publications and books related to productivity and lean product development, many threads relating to the methodology for productivity measurement and implementation could be connected with the philosophy of lean development.

The OECD study explained in 2.2.1 provided a platform for considering the relevant productivity measure for this research. In the case of an ESP, the more relevant productivity measure is the ‘Multi-factor Productivity’ (MFP) measure, due to the fact that both labor and capital (test facilities etc.) are used as inputs. As these inputs are not directly linked to the gross output but lead to value addition, the relevant measure is ‘Capital – Labor MFP (based on value added)’.

From methodological point of view, the case study of Mrs. Nachum mentioned in 2.2.2 was the guiding work for preparing relevant parameters and KPIs. The study is purely based on the service sector, meaning that it is a ‘Single-factor Productivity (SFP) also based on value added, somewhat different than the MFP based measure relevant for this research.

The dissertation of Mr. Kim as explained in 2.2.3, is an effort that is very specific to the construction industry. The hypothesis used by him to consider work hours and design quantities as a measure of productivity, may only serve the purpose of benchmarking. However, terming productivity as ‘production rate’ does not comply with the philosophy of lean. It does not even provide operational benefit as stated by (Fitzgerald & Moon, 1996): *“The value of productivity measurements is in their impact on the capability to manage and monitor, in order to reach a more efficient use of resources”.*

The Toyota Product Development System (Morgan & Liker, 2006) book is the holistic solution while considering the most productive or lean product development. As far as the topic of this research is concerned, it has no direct content regarding the productivity measurement. However, following the philosophy of lean, which is based on three pillars as shown in Figure 3, the productivity measurement may become merely a secondary need or say just a tool.

The LPDS contains many such tools, however it is not a tool kit. *“Engineers are engineers and tend to (…) reduce lean PD methodologies to technical tools. This does not work. Transforming to a viable lean product development system requires much more than a set of sophisticated tools; it necessitates a human system renaissance”* (Morgan & Liker, 2006, p. 334).

There are many sections in this book, which were taken as starting and guiding points for this research.

The book **Lean Innovation** (Schuh, 2013) also explains the transformation of lean production to product development termed as ‘Lean Innovation’. The five principles of lean thinking i.e. Customer value, Value stream, Flow, Pull and Perfection are explained in the language of product development process.

Altogether, after an extensive literature survey and study, it can be concluded that a value added MFP measurement method, specific for an automotive ESP is an appropriate approach for this research. This leads us to the next chapter, goals & requirements of the method.

3. Goals and requirements of the method

As explained in section Problem statement and Research objectives, the productivity measurement method aims to achieve following goals:

- Objective assessment of an ESP'S offer proposal for its productiveness, to ensure that the customer-defined value is covered with appropriate inputs (lean offer).
- Enable, generating benchmark data to compare future offers.
- Enable comparison of productivity for projects between offer and completion. The aim is to achieve continuous improvement in offer planning based on lesson learned.

To achieve these goals, following requirements are defined for the method:

- It should be easy to integrate in the offer process of the ESP. That means no drastic change in the offer workflow.
- It should cover the parameters that lead to the output of an ESP i.e. meeting customer-defined value.
- It should also include all input parameters (tangible and intangible) that are used in generating the defined output.
- The variables used to define the KPIs should be objectively available as data and controllable in order to take corrective measures.
- Although evaluated with the EDP, it should be flexible enough to be implemented in the productivity assessment of various other development processes of the ESP, as mentioned in subsection 4.2.4.

4. Development of method

This chapter covers the approach and its details in developing the productivity measurement method. The overview of the approach is shown in *Figure 4* below.

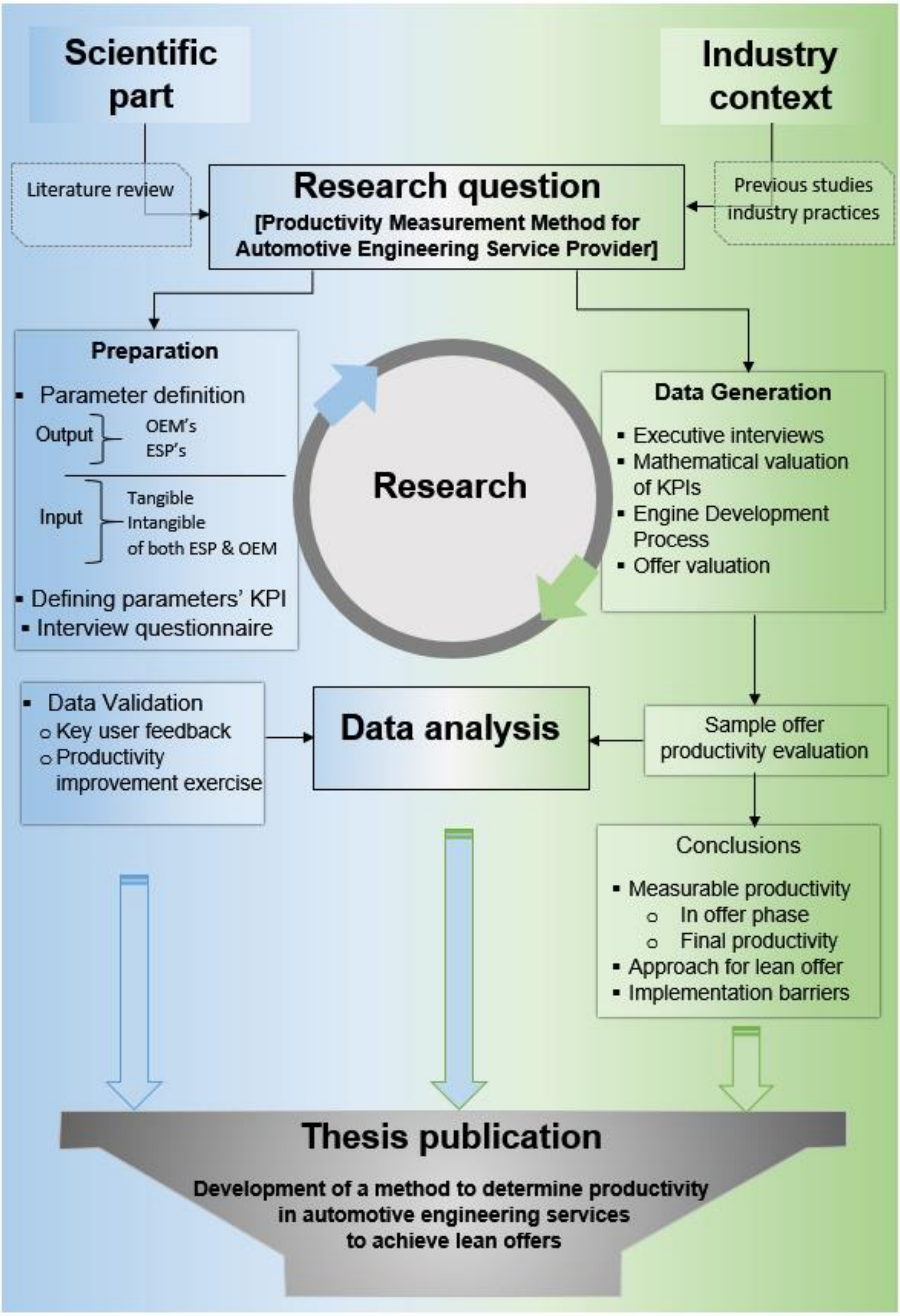

Figure 4: Research approach

The work of methodology development is continuously combined with scientific background information (left side of diagram with blue background) and the practical part (right side with green background).

4.1. Scientific preparation

The study for finding objective data to measure productivity, firstly required a detailed thought process regarding the parameters, which constitute the output & input. Secondly, the KPIs were defined in order to make these parameters operationally practical for both OEM as well as ESP. The last step was formulating a questionnaire to get the feedback from the ESP's as well as from the OEM's executives.

4.1.1. Parameter definition

"Productivity measures provide benchmarks for evaluating methods and for improving the use of resources" (McLaughin & Coffey, 1990) cited by (Nachum, 1999, p. 4).

Going back to the first principle of lean thinking i.e. 'Customer Value', the parameters that were considered for output, were viewed from the OEM's (customer) point of view. An ESP needs to tailor its output to meet the specifications of the contracting OEM. As such, the output of an ESP can't be standardized assuming similar quality standard as practiced in some other service industries e.g. number of kilowatt hours as the units of output of the electric industry; number of transactions as the units of output of commercial banks (Dean & Kunze, 1992) and number of contracted children as the units of output of day care centers (Bjurek, Kjulin, & Gustafsson, 1992).

To achieve this heterogeneous output, the input involves high content of innovative and thoughtful work. The inputs also differ in quantity and quality, due to the qualification, experience and intelligence of people.

To cover these variability in a frame where the influencing parameters are not missed was itself a challenge. The input parameters that lead to the quality of the output are difficult to quantify. Transforming such highly intangible parameters into operational measures, can create a conflict with some of the parameters that are rather clearly measurable.

“While intangibles may be an inherent problem, they are not an excuse for avoiding productivity analysis (...) intangibility makes measurement difficult, but it is seldom a reason to avoid measurement even if proxies must be used” (McLaughin & Coffey, 1990, p. 47)

The parameters were defined keeping this background in mind. These definitions were made together with a team of experienced people from the areas of Process Development, Project Management, Project Operations and Product Management.

As this topic needs a detailed explanation, it is further covered in Chapter 4.3. The parameters are listed below.

Category		Parameter (detail subsection)	Explanation
OUTPUT Parameters	Output of **OEM**	Time to Market (4.3.1.1)	Parameters for OEM’s output to its end customer, in which the usefulness of ESP’s output is important.
		Competitive Edge (4.3.1.2)	
		Reliable product –Robustness of solution (4.3.1.3)	
	Output of **ESP**	Maintaining timeline (4.3.1.4)	These parameters contain contractual targets.
		Meeting specified targets (4.3.1.5)	
		Flexibility (4.3.1.6)	These are intangible outputs of ESP which add value in OEM’s project & organization.
		Improving processes of OEM (4.3.1.7)	
INPUT Parameters	Input of **ESP**	Test facilities (4.3.2.1)	These are tangible inputs used by ESP.
		Manpower (4.3.2.2)	
		Knowledge stock (4.3.2.3)	These parameters represent the value of intangible resources used by ESP.
		Knowledge through research (4.3.2.4)	
		Knowledge spillover (4.3.2.5)	
	Input of **OEM**	Hardware (4.3.2.6)	Value of HW used by ESP
		Data (4.3.2.7)	Value of data useful for ESP

Table 2: List of productivity measurement parameters

4.1.2. Defining parameter KPIs

Quantifiable KPIs that are well linked to the business’s overall objective, are essential for monitoring the progress of strategic and operational goals in organizations and/ or comparing the financial performance within its industry (Investopedia, 2017).

In general, the KPI must have following characteristics (Folnovic, 2013):

- Quantitative: presentable in form of numbers
- Practical: exist in current company processes
- Directional: helpful to check if the performance is getting better
- Actionable: can be put into practice to achieve the desired change

For a productivity measurement method, which is useful for achieving the goal of lean offers, a definition of KPIs for the input and output parameters meeting the above mentioned characteristics, was the key topic.

An initial version of KPIs for creating a common understanding amongst the OEM’s and ESP’s executive was used during the interviews. A ‘*’typical sequence for developing KPI’’* (Baroudi, 2014), as shown below, was kept in mind:

i. Identify the objective
ii. Develop a view on how the result will look
iii. Develop a process for how you want to achieve the objectives
iv. Define effectiveness before efficiency
v. Prioritize the KPIs for stakeholders
vi. Develop output KPIs before input KPIs
vii. Select the best fit KPI

However, due to the heterogeneous profiles of the executives, OEM’s geographic location and product representation e.g. on-road/ off-road, the finalization of the KPI’s needed several iterations, for some of the above mentioned steps.

As the KPIs are closely coupled with the productivity parameters, their explanation is made in chapter 4.3 in-line with these parameters. Below is the overview of the KPIs. The quantitative representation of these KPIs in the context of the ESP’s industry is explained in subsection 4.2.1.

Category		Parameter	KPI
🟩		Time to Market	The development time allocated by the OEM & ESP’s contractual time

Category		Parameter	KPI
OUTPUT Parameters	Output of **OEM**	Competitive Edge	Specifications defined as USP[3] which must be demonstrated by ESP
		Reliable product – Robustness of solution	Verification of sensitivity of design
	Output of **ESP**	Maintaining timeline	Contractual timeline
		Meeting specified targets	Acceptance criteria in contract
		Flexibility	Project Variation Requests (PVR[4])
		Improving processes of OEM	Value of documents carrying knowhow (excl. reports) shared by ESP to OEM
INPUT Parameters	Input of **ESP**	Test facilities	Value of test facilities
		Manpower	Value of total manpower
		Knowledge stock	Value of knowledge extracted from manpower costs
		Knowledge through research	R&D expenses scaled to project value
		Knowledge spillover	Rate of employee turnover [5]
	Input of **OEM**	Hardware	Value of HW used by ESP
		Data	Value of data provided by the OEM, which saves efforts for the ESP

Table 3: List of KPI's for the defined productivity parameters

4.1.3. Development of questionnaire

After the engineering productivity parameters and KPI definitions were finalized, a paper version of the questionnaire was developed to get these parameters rated (in

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[3] USP: Unique Selling Proposition is feature differentiating itself from competitors and adding value for the customer

[4] PVR: A document containing the deviations from original contract by both OEM & ESP. These deviations can be of specifications, additional resources etc.

[5] Employee turnover: Refers to percentage of employees who leave a company voluntarily or involuntarily and are replaced by new employees.

terms of weighting factor) from various executives. The ratings were used for valuation of the KPIs as explained in subsection 4.2.1.

The final version of the questionnaire is shown in Appendix 1.

The questionnaire was divided into two areas viz. output & input.

The output was divided into two categories:

i. Output of the ESP
ii. Output of the OEM

A weighting factor was kept as an entry field for the executives, to rate these two output categories to make a sum of ‘1’.

Each of these categories were then sub divided in parameters. The parameters of the respective category, were provided again as entry fields for the executives, to rate them in order to get a sum of ‘1’.

When all parameters, multiplied by the weighting factor of the respective category, are summed up, the end result would be again ‘1’.

Similarly, the input was divided into seven parameters, which can be grouped in two categories (the sole purpose of the grouping here is to provide an overview and not to make any weighting)

i. Input from the ESP i.e. labor, test facilities and knowhow
ii. Input from OEM to ESP e.g. Hardware for testing and data

Also for the inputs, a weighting factor was given as entry field for the executives, to rate them in order to get a sum of ‘1’.

4.2. Data generation

4.2.1. Mathematical functions for parameters

As explained in subsection 4.1.2, the KPIs were defined considering the scientific background and updated during the executive interviews to represent the industrial context.

Along with this, the important task of assigning quantifiable functions to all these parameters started. *“A large list of KPIs that does not have clear linkages to (…) overall objective may be a sign of a larger problem: a lack of (…) strategic focus.”*

(Baroudi, 2014). Knowing this and for meeting the whole purpose of the ESP's productivity measurement, clearly measurable KPIs, represented with the same unit (Euro) was an obvious necessity.

For the mathematical presentation, the KPIs and other entities are represented by variables. Variables common for all functions are defined below. Variables, which are specific to a parameter, are defined in the corresponding subsections in chapter 4.3.

Common variables:

$W_p \coloneqq \text{Weighting factor for the respective parameter 'p'}$

$V_c \coloneqq \text{Contract value of project}$

Functions for output parameters:

The OEM pays a price for a project (V_c), in which it expects the delivery of parameters as defined in subsection 4.1.1. The weightage for these parameters (W_p) was collected through the executives' interviews of OEMs as explained in subsection 4.2.2.

In theory, if the ESP fulfills the deliverables for all parameters, the value of each parameter will be equal to the project contract value multiplied by the weighting factor of that parameter. This value of each parameter was calculated with a function using the KPI of that parameter.

By using these functions, the total output can be assessed in the offer phase as well as after the completion of project. There is a theoretical probability that all the parameters are delivered meaning 100% output, however there also exists a probability that some of the parameters exceed the expectation and some do not.

The weighted assessment of the parameters in the offer phase can also help in customer oriented project execution.

Functions for input parameters:

Unlike the output, where the project value represents the 100% fulfillment of all parameters, the input parameters contain the costs incurred by the ESP.

In theory, the total costs for all parameters, represent 100% input. The value of every input parameter is calculated with the function using the KPI of that parameter. Here, the weighting, which was given by the executives, is only used to review the planned distribution of total input cost amongst the input parameters.

Out of the 5 inputs parameters, 3 are intangible parameters, whose value gets undermined in absence of a correct function. This can lead to very high hidden costs which are added to the tangible inputs and finally resulting in low productivity.

By assessing all the tangible and intangible costs with appropriate functions, right balance can be planned during the offer phase.

4.2.2. Executives' interviews

The aim of the interview was to get the ratings for the output and input parameters. The executives from various OEMs, as shown in Table 4, were requested to provide these ratings, based on their experience in working with various ESPs over several years. While doing so, they were also requested to consider neutrality concerning past experiences and focus on their requirements. The choice of executives was made to cover a good representation of various products, roles of the executives and geographic locations of OEMs.

Although these ratings were accepted as given by the executives, in case of a remarkable difference compared to others', the executives were asked to provide a justification for such ratings. With this, any misinterpretation of the parameters could also be avoided.

The results of these interviews with the OEM's and important discussions are provided in subsection 5.1.1. Following the principle of 'Customer Value', the ratings provided by the executives of the OEMs were used for the mathematical valuation to develop the productivity metrics.

Nonetheless, it was also very important to get the ratings of ESP's executives (Table 5). Such an exercise could provide an immediate reflection of any gaps, which may exist in understanding the customer. Before the implementation of any productivity measures, bridging these gaps would be the first step.

The results of the ESP's interviews are provided in subsection 5.1.2. However, these results are only used for gap analysis and assessing the future implementations topics. They are excluded from the mathematical valuation.

Following executives were interviewed:

OEM	OEM’s country and automotive business	Executive’s role
AB Volvo Penta, Sweden	Volvo Penta is a global, world leading supplier of engines and complete power solutions for marine and industrial applications.	Head of Testing
SAME DEUTZ FAHR Italy	SDF is one of the world's leading manufacturers of tractors, harvesting machines and Diesel engines.	Head of Engine R&D
Jaguar Land Rover U.K.	JLR is UK’s largest automobile manufacturer of high end cars and SUVs.	Purchasing manager, Engineering services & non production purchasing
Volvo Trucks France	Formerly Renault Trucks, manufacturer of trucks and buses	Group manager Control system hardware
Simpson & Co. Ltd. India	Manufacturer of engines for agriculture, industrial applications and power generation.	Executive vice president Engineering and R&D

Table 4: Profile of OEM’s executives

ESP’s skill area	Executive’s role
Product Management	Business field leader, On road commercial powertrain systems
Operations	Technical field leader Powertrain project management, operations and Quality Management
Project Operations	Director project operations, High Performance Cars
Program Management	Program & project manager, Powertrain systems

Table 5: Profile of ESP’s executives

4.2.3. Offer data

The offers are estimated using a MS Excel offer template. The offer follows a structure of the project time plan, derived from the development process and aligned with the milestones of OEM’s product development plan.

The values for inputs of the ESP (see 4.3.2.1, 4.3.2.2, 4.3.2.3 & 4.3.2.6) are available as a result of this estimate analysis.

For making plausibility checks and perform the offer valuation, methods like budget burn rate[6], manpower distribution charts and resources pie charts are used.

4.2.4. Reference development process

As mentioned in section 1.3, offers based on AVL's EDP is taken as an example to gather data. There are similar processes existing e.g. Powertrain Development Process (PDP), Transmission Development Process (TDP), Battery Development Process (BDP), etc. however the EDP is established since the year 1998 and since then many offers have been made based on it. Using this as a basis for the methodology validation, provided stable offer data.

A brief overview of the EDP relevant for this research is explained below.

The EDP consists of four main phases of development. These are: Concept, Prototype, Pre-production and Production validation.

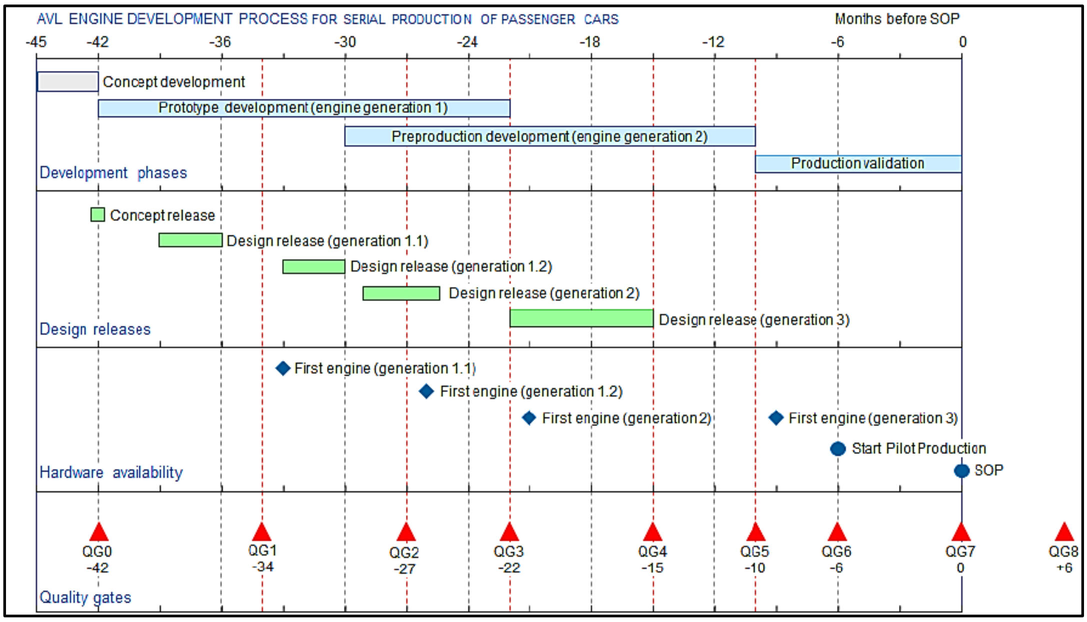

Figure 5: AVL's EDP for a passenger car engine

4.2.4.1. Concept development

This is a virtual phase, in which the design solutions are evaluated. Early simulations, to assess the technology solutions, required in meeting the specifications are performed. Here the front-loading methods are applied (see also subsection 2.1.2).

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[6] Budget burn rate: is a rate at which the planned budget is consumed.

At the end of this phase, the engine architecture, under agreed boundary conditions with the OEM, can be confirmed. The packaging for all intended vehicle installation also gets confirmed.

The Quality, Cost, Weight & Functionality (QCWF) targets of OEM are firmed up.

4.2.4.2. Prototype development (Generation 1)

In this phase, the concept design from the previous phase is further developed in line with the QCWF targets. The design is continuously optimized using simulations, in order to get high confidence for the prototype hardware.

The phase includes two stages of prototypes as explained below:

Prototype generation. 1.1: This stage covers hardware made with rapid prototype methods and/or soft tools. The purpose of this is to make performance development to reach the targets and to check functions and mechanical integrity of the whole engine.

Prototype generation 1.2: Based on the test results of generation 1.1 hardware, the design is updated to this prototype level. The aim of this stage is to get prototype hardware that can be used for destructive testing to check initial durability of components. The results of hardware test are necessary to get a design maturity, required for releasing the drawings of long lead parts and production intent soft tooling.

The performance, functionality and initial durability tests are completed. Bench level calibration for supporting testing in vehicle is provided.

4.2.4.3. Pre-production development (Generation 2)

The Generation 2 development is aimed to translate the prototype engine to mass production readiness. It consists of two design phases.

First, the design (called as Gen.2) is updated based on the results of the previous generation and the hardware based on this design is tested for complete functionality and durability.

Secondly, the design is updated for the mass production release, in parallel to the testing of Gen. 2 hardware. During this, the production intent tooling is also released.

The completion of testing using hardware from Gen.2 is aimed to fulfil all engineering contractual targets (performance, emissions and functionality). Calibration on test bench is completed to support all kinds of testing.

The QCWF targets, including the customer-defined durability targets are confirmed.

4.2.4.4. Production validation

The last phase is the final validation of the production components. First, hardware that is produced using production tooling (off-tool) is validated, followed by hardware using production process (off-process).

The durability tests are performed with hardware from production processes to confirm reliability topics. Homologation tests for legislation compliance are performed to enable sale on market.

4.3. Productivity parameters

Continuing from the background explained in subsection 4.1.1, the parameters, which are considered necessary for the measurement of output & input are listed and explained below. The KPIs are explained in-line with the parameters. A mathematical function for converting the KPI to a measurable value, is defined at the end of every parameter.

For the mathematical presentation of all functions, their KPIs and other entities are represented by variables. Variables common for all functions are defined below. Variables, which are specific to a parameter, are defined in the corresponding subsection.

Common variables:

$W_p \coloneqq \text{Weighting factor for the respective parameter 'p'}$

$V_c \coloneqq \text{Contract value of project}$

4.3.1. Output parameters, KPIs and functions

Defining the output of an automotive ESP was the most difficult aspect of this research. When an OEM buys some services from an ESP, it has decided that this service will have a certain value which he is ready to pay. This evaluation is performed through business case analysis, in-house development cost calculation, etc. So what are the contents of the services, for which the OEM is making payments? Is it data, design, a tested product or more?

In Figure 2, the contribution of an ESP in the PCP of an OEM was shown. Looking at this figure, it becomes very clear that the output of an ESP is incorporated in the OEM's process and typically needs further work in production processes, to produce a final product that is delivered to the end customer of the OEM.

As such, not only the output of the ESP, as committed in the contract but also its usefulness to the OEM's output need consideration. To address this, the output was divided in two categories.

- **Output of the OEM**
- **Output of the ESP**

These are explained in detail below.

Output of the OEM

In spite of knowing that accurate data may not always be available for this category, it was still considered. The reasons behind this consideration are:

- If the OEM cannot use the ESP's output to create a product, then the output of the ESP would lose its value (see subsection 2.1.1).
- The priorities of the OEM, in terms of quality (specification contents) for the project need to be understood.
- Even if some of the data cannot be predicted or carried over, constants based on ESP's own assessment or competition analysis can be used.

Three parameters are considered to be relevant for this category. To connect these parameters to the ESP, the consideration was always given to the usefulness of the ESP's output for the OEM and not to the factors beyond ESP's influence. This means that the values of the KPIs are scaled to the project value paid by the OEM.

4.3.1.1. Time to market (TTM)

TTM is the duration from the concept approval[7] to the start of selling. TTM is very important for 'First of its Kind'[8] products due to the advantage it can provide from price skimming[9].

An OEM has the most dominating influence on meeting the set TTM target. There are severe effects of not reaching the TTM, viz. loss of profit, losing probable market/ product leadership, etc. If the intended new product is meant for replacing an old product, in the extreme case the delay means the absence of the product in market, as the old product has reached the end of the production life cycle.

As the TTM is a planned parameter, the ESP needs to provide its development time agreeable for the OEM. Here three scenarios arise:

i) The ESP agrees to the OEM's allocated development time → The TTM stays as planned.

ii) The ESP convinces the OEM to make the development in shorter time by using methods explained in subsection 2.1.2 → The TTM can be reduced or the OEM may choose to use this as a buffer for unforeseen eventualities.

iii) The OEM agrees to the longer development duration proposal of the ESP → for maintaining the TTM, the OEM needs to plan more resources for other tasks.

The time agreed from one of these scenarios, becomes the contract development time. Maintaining contract development time is considered in the output of the ESP (see subsection 4.3.1.4)

KPI of TTM:

The agreement about development time from one of above mentioned scenarios leads to the KPI of the TTM.

Following variables are defined to arrive at the function of TTM:

$t_{d,OEM} \coloneqq \text{OEM's initially allocated development time}$

$t_{d,c} \coloneqq \text{Contractual development time}$

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[7] Concept approval: This is the milestone where an evaluation of the product need, benchmarking and basic concept evaluation is completed and approved by the management to start the concept design work.

[8] First of its kind: A product that is made available to the consumer for first time in in the market.

[9] Price skimming: A pricing strategy to get the advantage of uniqueness in the market

Function of TTM:

$$F_{TTM} = \frac{t_{d,OEM}}{t_{d,c}} \cdot W_{TTM} \cdot V_c \tag{1}$$

4.3.1.2. Competitive Edge (CE)

“Competitive Edge is having a clear advantage over the competition in terms of one or more elements of the market mix that is valued by potential customers. The market mix is the seven P’s of marketing: Product, Price, Place, Promotion, People, Process & Physical evidence.” (Simister, 2011)

An ESP can only influence the Product part of the seven P’s objectively. Regarding product; criteria like design, technology, usability and quality are mentionable and are part of deliverables for the ESP.

During the contract phase, specifications with clear targets are defined by OEMs (see subsection 4.3.1.5). Depending on their end customer market, the OEMs rank some of the specifications as priority specifications or ‘USP Specifications’ (USPS) which will give them competitive edge.

Apart from the contract targets, the USPS are also defined with ‘engineering targets’[10].

Using the knowledge earned through R&D (see subsection 4.3.2.4) and knowledge stock (see subsection 4.3.2.3), an ESP can meet or even surpass the USPS engineering targets defined by the OEM.

KPI of competitive edge:

An indicator of this parameter is taken as the number of USPS that meet or surpass the engineering targets, compared to the total number of USPS given by OEM.

Following variables are defined to arrive at the function of competitive edge:

$U_c \coloneqq \text{Number of USPS given by the OEM}$

$U_{c+} \coloneqq \text{Number of USPS meeting the engineering targets}$

Function of competitive edge:

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[10] Engineering target: Values better than the contract targets. Whereas the contract targets are mandatory to be fulfilled, the engineering targets are an indication to be reached.

$$F_{CE} = \frac{U_{c+}}{U_c} \cdot W_{CE} \cdot V_c \qquad (2)$$

This parameter represents mainly the reality during project execution. However, the engineering targets are agreed in offer phase to create contract. As such, for productivity assessment during the offer phase, the variable 'U_{c+}' is assumed to be same as variable 'U_c'.

4.3.1.3. Reliable product - Robustness of Solutions (RS)

The final output of an OEM is the product for its customer, for which, high product reliability[11] is always a top priority criterion in the automotive sector.

An ESP does not have much direct influence on the product reliability, because of the processes, assembly, transport conditions etc., through which the product is built at OEM. However, the foundation of this product reliability is laid during engineering. For this reason, **'robustness of solutions'** provided by the ESP is the parameter considered as useful and measurable.

The design and development performed by the ESP shall be less sensitive to variables. If too many sensitivity features are incorporated in the engineering solutions (e.g. tolerance stack-ups, too many special tools and procedures for assembly and servicing, etc.), the product becomes less reliable. Reliability issues need re-engineering, lead to recalls and hurt the product image. Less robust solutions also need expensive quality control measures in production.

KPI for robustness of solutions:

The specifications that are defined by the OEM as the acceptance criteria can be assessed for sensitivity.

Tolerance stack up studies and sensitivity measurements are common in development. A proof of sensitivity study, using components meeting the OEM's intended process capability provides value and confidence of meeting performance targets under extreme engineering circumstances.

Following variables are defined to arrive at the function of reliable product:

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[11] Product reliability: The probability with which the product will deliver its performance, for the intended life under the stated conditions.

$S_r :=$ Number of required sensitivity tests

$S_p :=$ Number of passed sensitivity tests

Function for robustness of solutions:

$$F_{RS} = \frac{S_p}{S_r} \cdot W_{RS} \cdot V_c \tag{3}$$

Sensitivity tests on hardware represent the reality during project execution. So the performance indicator can only be fulfilled after the completion of the project. During the offer phase, the value for number of passed sensitivity tests remain ‘0’ (zero).

Output of the ESP

An ESP is bound to deliver at a given time, the contractual deliverables in terms of specifications, in form of data or demonstration of performance on prototypes. For these deliverables, payments are made by an OEM.

During the discussions with some executives, it became obvious that many OEMs also make their preference ratings for an ESP, based on non-contractual output (soft output). Most of them are sometimes ready to pay a higher price for these soft outputs. These parameters, ‘Flexibility in finding solutions’ and ‘Process improvement at OEM’ are explained below.

4.3.1.4. Maintaining Timeline (PT)

For meeting the TTM target (see subsection 4.3.1.1), a contractual agreement regarding the development time, takes place between the OEM & the ESP. The delivery of necessary outputs at the ‘Quality Gates’[12] and ‘Milestones’[13] over the development period becomes highly important.

A shorter actual development time can further improve TTM for the OEM. However, a delay would worsen the TTM and the OEM may have to deploy more resources in short time. This difference between the contractual and actual development time, shall be related to the TTM, for appropriately evaluating the effect on the final product.

KPI for maintaining timeline:

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[12] Quality gates: Clearly defined quality criteria for successful completion of a project phase.

[13] Milestones: Represent the delivery of important work processes. They are located between two quality gates.

The planned timeline and actual timeline are simple entities measured with tracking Gantt charts in the project plan.

Following variables are defined to arrive at the function of meeting specified targets:

$t_{d,c} \coloneqq \text{Contractual development time}$

$t_{d,a} \coloneqq \text{Actual development time}$

Function for maintaining timeline:

$$F_{PT} = \left[W_{PT} - \frac{(t_{d,a} - t_{d,c})}{t_{d,c}} \cdot W_{TTM}\right] \cdot V_c \tag{4}$$

This parameter represents the reality during project execution. However, the development time is agreed in the offer phase to create a contract. As such, for productivity assessment during the offer phase, the variable '$t_{d,a}$' is assumed to be same as variable '$t_{d,c}$'.

4.3.1.5. Meeting Specified Targets (ST)

The development contracts generally have non-negotiable targets (legislation or defined hard technical targets) and negotiable targets (interdependent technical targets). The non-negotiable targets are excluded from ratings because everyone has to meet them.

These targets and their values (acceptance criteria) are defined by the OEM after performing intensive studies of market requirements, competition, manufacturability, etc. The acceptance criteria are mostly interdependent and achieving the best value for each of them may not be possible. Thus, the best product is often the best compromise made amongst these targets which meets the market needs.

The acceptance criteria in the automotive branch include amongst many, following important:

- Product costs
- Power & Torque
- Fuel consumption
- NVH
- B_{10} lifetime[14]

An OEM may define one of these as a hard target.

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[14] B_{10} lifetime: The usage in field (hours or km), by which 10% of the sold products have failed.

KPI for meeting specified targets:

This is a rather straight forward KPI. Number of acceptance criteria that are defined as contractual targets are the indicators.

Following variables are defined to arrive at the function of meeting specified targets:

$AC_c \coloneqq \text{Number of acceptance criteria defined in the contract}$

$AC_f \coloneqq \text{Number of acceptance criteria fulfilled}$

Function for meeting specified targets:

$$F_{ST} = \frac{AC_f}{AC_c} \cdot W_{ST} \cdot V_c \tag{5}$$

This parameter like the USPS represents the reality during project execution. However, the acceptance criteria are agreed in the offer phase to a create contract. In order to meet the contract requirement, for productivity assessment during the offer phase, the variable 'AC_f' is assumed to be same as variable 'AC_c'.

4.3.1.6. Flexibility (FS)

The automobile market is changing very fast since last decade. Product specifications that are defined based on market surveys, may become obsolete by the time the product is developed. E.g. the trend of downsizing an IC engine dropped its ranking from #2 to #10 within a year, battery electric vehicle stepped up its rank from #9 to #1 within two years (KPMG International, 2017, p. 9).

To sustain the product usability for the end customer and the company market interests, the OEMs need to change the specifications and/or the timeline. An ESP's flexibility to react to these changes and actively work in finding alternative solutions to avoid an impact on the OEM's market interests (see 4.3.1.1 & 4.3.1.2), is an important aspect looked at by the OEM during the selection of an ESP. During the project execution, this also becomes a key confidence building measure between the OEM and ESP.

Such changes in specifications/ timeline are documented in a system called Project Variation Requests (PVR). Its commercial impact is handled through claim management. A PVR may be defined for many different changes and depending on the project status, may or may not have a commercial impact. Sometimes the OEM needs to pay for the additional efforts in the PVR or sometime the ESP may save some efforts, whose value is credited to the OEM or they may also be cost neutral. These changes are often documented in a list called the ‘Plus-Minus List’

KPI for flexibility in finding alternative solutions:

The indicator for this is taken as the value of PVRs agreed during the project execution.

The variable required to define the function of flexibility is:

$V_{PVR} \coloneqq V\text{alue of a PVR}$

Function for flexibility in finding alternative solutions:

$$F_{FS} = \sum |V_{PVR}| \cdot W_{FS} \tag{6}$$

As this parameter represents the reality during project execution, it cannot be pre-planned for productivity assessment during the offer phase. So the performance indicator can only be fulfilled after the completion of the project. During the offer phase, the value of PVRs remains ‘0’ (zero).

4.3.1.7. Improving processes of OEM (IP)

The OEMs generally use their generic PCP as base and adapt for the new product development. The ESP performs number of development project with various OEMs. Such experience brings continuous improvement into the generic development process pursued by the ESP. A result of this can be a reduction of the development time (see subsection 4.3.1.1).

As explained later regarding the data from OEM (see subsection 4.3.2.7), where know-how flows from an OEM to an ESP in form of procedures, guidelines, etc. a reverse know-how flow can also occur.

Especially for OEMs in Asian countries and OEMs who have a long product life cycle (off-road, marine, construction equipment), the provision of test standards, guidelines, the DVP&R[15] and procedures therein are considered as a valuable output. Such know-how transfer helps the OEM to perform production validation and development tests on their own.

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[15] DVP&R: Design Verification Plan and Report

The reports, as generated for the deliverables, are not considered as a part of the know-how transfer.

KPI for improving processes:

The indicator of the know-how transfer by an ESP shall be objectively linked with the number of officially released documents (procedures, guidelines, templates, etc.). The value of these documents is assigned by the ESP as common practice.

The variable required to define the function of improving processes is:

$V_{D,ESP} \coloneqq \text{Total value of all released documents}$

Function for improving processes:

$$F_{IP} = V_{D,ESP} \tag{7}$$

As this parameter represents the reality during project execution, it cannot be pre-planned for productivity assessment during the offer phase. So the performance indicator can only be fulfilled after the completion of the project. During the offer phase, the value of documents remains ‘0’ (zero).

4.3.2. Input parameters, KPIs and functions

The inputs used by the ESP for delivering the outputs are grouped in two categories.

- **Inputs of the ESP:** This includes both tangible and intangible inputs.
    - The tangible inputs are the measurable inputs like manpower and resources that can be clearly counted.
    - The intangible inputs are more difficult to count. Mainly the knowledge and experience in various forms falls into this category.
- **Inputs of the OEM:** This also includes both tangible and intangible inputs.
    - The tangible input includes hardware for testing, fitment trials etc. provided to the ESP. This material has a value which is used by the ESP as input for the development work.
    - Intangible inputs such as valuable information in terms of previous design, field data, production constraints etc., can help the ESP to start from an already available base and avoid redundant work.

Apart from having influence on the output, the input parameters have also an influence on each other. E.g. using more knowledge stock shall normally lead to a lower total manpower or using OEM’s experience shall also lead to lower total manpower of the ESP. This is explained in each parameter below.

Input of the ESP

4.3.2.1. Test Facilities (TF)

During development, infrastructure like test rigs, test benches, measurement equipment etc. is needed. These facilities generally have their own cost structure which is formed on the basis of its investment cost, utilization and maintenance cost. While planning a project, the test facilities are calculated depending on the project content.

The infrastructure which the personnel need (office, computers, etc.) are not considered in facilities. They are included in the hourly rates of the personnel.

KPI for test facilities:

The total number of hours of test facilities or costs of test facilities are an indicator.

Subsequently, the variable for the function of test facilities is:

$C_{TF} \coloneqq \text{The total cost of facilities planned in the project}$

Function for test facilities:

$$F_{TF} = C_{TF} \tag{8}$$

4.3.2.2. Manpower (MP)

The cost of personnel working in the project is represented by this parameter. Similar to the production industry, also in engineering services, the division of labor[16] is very important.

The manpower is divided into four categories as below:

- ***Management*** – People doing project management and supplier management
- ***Highly experienced*** – 'Chief Engineers' (CE) with deep technical knowledge of the product and its application in market and 'Lead Engineers' (LE) with deep knowledge of the defined skill area e.g. design, analysis, testing etc.
- **Skilled** – Engineers with good knowledge of their area, who can work independently or with little guidance
- ***Workers*** – All other people performing their allocated tasks guided by others

While collecting the parameter ratings during the executive interviews, the distribution for this division was also collected. This means, if the manpower is considered to be

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[16] Division of labor: is allocation of specialized task to different skills of labor aimed to improve efficiency.

100%, then what is the contribution of each of the four categories. The intention was to get an understanding of how the executives assess the correlation of between these four categories.

KPI for manpower:

The total number of manpower hours for the project is an indication of this parameter. But this is not so straight forward. Because, the parameter Knowledge stock (see subsection 4.3.2.3) draws its data from this parameter (i.e. from the knowledge aspect of skilled and highly experienced people), this value of knowledge stock needs to be subtracted from the total manpower.

Following variables are defined to arrive at the function of manpower, wherein the function of the value of knowledge stock will be defined later.

$C_{MP} \coloneqq \text{The total cost of manpower planned in the project}$

$F_{KS} \coloneqq \text{Function of knowledge stock (derived value)}$

Function for manpower:

$$F_{MP} = C_{MP} - F_{KS} \tag{9}$$

Note: The reason for generating a separate parameter for knowledge stock is to assess its proportion to the total manpower costs. A balanced proportion ensures highest efficiency amongst the manpower.

4.3.2.3. Knowledge Stock (KS)

The accumulated knowledge is an asset, which helps in shortening the ‘Learning Curve’[17] during a project, thereby reducing the direct manpower and improving the productivity. The knowledge stock can be in form of experienced people, as well as guidelines and procedures laid out and updated by them.

People are already considered in direct manpower under subsection 4.3.2.2 and the guidelines/ procedures are too minute details to be considered as KPI. Cumulative investment in the acquisition of knowledge/ training measured over a period of some years (Nachum, 1999, p. 12), was not considered as an indicator because the relevance of training to the technical skill is rare to find.

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[17] Learning Curve: Is time taken by a person or team to reach a level in delivering useful output during a new task or project.

But this parameter cannot be ignored, as it reflects in the direct manpower. The higher the involvement of experienced people, the lower should be the number of workers. It should not be too high either, because, then the purpose of division of labor gets defeated.

KPI of knowledge stock:

The four classifications of manpower as explained in subsection 4.3.2.2, have hourly rates (i.e. cost) according to their skill level. The minimum is represented by the worker, as he/she needs instructions and guidance from others. Considering that this is the minimum level of knowledge requirement for a job in the ESP's company, the hourly rates of skilled and highly experienced people are higher due to the knowledge they possess. People performing project management and supplier management are excluded from this difference, because this function is required for operations and not for knowledge.

This difference of costs due to the knowledge level, is the indicator of knowledge stock.

The variables, such as hourly rates, total costs and cumulative work hours of different employees shall be denoted with corresponding indices. These are 'e', 's' and 'w' meaning 'highly experienced', 'skilled' and 'worker' respectively. The hourly rates are calculated from the total costs and work hours, which are indicated as following:

$C_{e,s,w} \coloneqq \text{Total costs of each category of employees}$

$t_{e,s,w} \coloneqq \text{Total work time of each category of employees in hours}$

$R_{e,s,w} = \frac{C_{e,s,w}}{t_{e,s,w}} \coloneqq \text{Hourly rate of each category of employees}$

Function of knowledge stock:

$$F_{KS} = (R_s - R_w) \cdot t_s + (R_e - R_w) \cdot t_e \tag{10}$$

4.3.2.4. Knowledge through research (KR)

The ESP's business is mainly based on providing appropriate technical solutions to the customers. For providing these solutions, new technologies and state of the art engineering methods need to be acquired through research and development (R&D). Note: The projects, which OEMs outsource to the ESP, are often called as R&D in the OEMs' organization. The R&D of an ESP is clearly distinguishable with that of an

OEM, by the fact that is mostly a general research without focus on specific customer product.

Although the learning through R&D cannot be immediately converted to output and increases the costs in short term (Zvi, 1998, pp. 17-45), it is still considered an important measure. The short term effect of R&D topics and publications is, that they help in winning projects and thus justify the consideration of their costs in the inputs.

KPI for knowledge through research:

The R&D expenditure is considered as an indicator.

The variables required to define the function of knowledge applied through R&D are:

$C_R \coloneqq \text{Expenditure on R\&D from previous year}$

$TO \coloneqq ESP's\ \text{Turnover from previous year}$

Function for knowledge through R&D:

$$F_{KR} = \frac{C_R}{TO} \cdot V_c \tag{11}$$

[(R&D expenses from previous year ÷ turnover from previous year) x project contract value]

4.3.2.5. Knowledge Spillover (SO)

"Spillovers occur if an innovation or improvement implemented by a certain enterprise increases the performance of another enterprise without the latter benefiting enterprise having to pay (full) compensation" (van Stel & Nieuwenhuijsen, 2002).

Unlike the knowledge acquired through own research (covered in 4.3.2.4), knowledge can also be acquired through others' R&D or work. Since the evolution of social networks, forums and open platforms, knowledge exchange is making a vital impact on the methods of in-house knowledge acquisition of the firms. As such including this parameter as an input becomes necessary.

While focusing on knowledge spillover through R&D, (Dumont & Meeusen, 2000) discussed different aspects of knowledge spillovers. E.g. supplier-buyer knowledge, conferences & symposiums, voluntary exchange of information for trade reasons, etc. However, the measurement of such spillover is very challenging due to the lack of data.

The most relevant knowledge spillover in automotive industry can be described by the Marshall-Arrow-Romer (MAR) theory, which is based on the interaction of companies, through individual persons within the same industry (Glaeser, Kallal, Scheinkman, & Shleifer, 1992). Although, the unofficial person to person interaction is not measurable, interaction happening due to the movement of employees within the industry is the main and measurable source of this spillover. Due to this movement, some existing knowledge may flow out of the company, which then needs replacement and as such adding the costs of used inputs. Nevertheless, there may also be an addition of experienced employees, which bring in the knowledge.

KPI of knowledge Spillover:

The employee turnover is considered to be the representative indicator for this movement. A low employee turnover within a project (team stability) is always an important factor for its success. In this, the employee attrition is not considered. Because in the case of attrition, the employee is not replaced.

Additionally, to the manpower costs (C_{MP}, defined in 4.3.2.2), the variable for the dimensionless 'employee turnover rate'[18] needs to be declared:

$T\dot{O}_E \coloneqq \text{Employee turnover rate}$

Function of knowledge spillover:

$$F_{SO} = T\dot{O}_E \cdot C_{MP} \tag{12}$$

Input of OEM

When an OEM contracts an ESP, it also needs some of its own labor and test material. The administrative work that is required to coordinate with an ESP is neglected here as it depends a lot on the organization structure of the OEM and its systems.

The cost of hardware and engineering information are important parameters, which need to be accounted as inputs for the ESP.

4.3.2.6. Hardware Costs (CH)

The development requires hardware and prototypes to perform 'Verification and Validation' (V&V) tests. As a common practice, the prototype hardware is supplied by

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[18] Employee Turnover rate: Number of employees who have left the organization within the year divided by (the number of employees at the beginning of the year + number of new appointments made within the year)

the OEM. For newly designed components, the hardware costs include material, supplier engineering, tooling and logistic costs. For carry over parts (COP), only the OEM's internal material and logistic costs are involved.

Unless a completely new technology or product generation is evolved, the OEM intends to use carry over or 'off the shelf parts'[19], as much as possible. To keep the complete development costs at a minimal level, the ESP must strive to engineer the product using the right balance of new, COP & off the shelf parts. Such a mix also reduces the efforts (time and costs) required for the V&V.

Apart from this, the use of a target oriented V&V plan is also the key to keep the prototype costs to a minimum level.

Sometimes, the OEMs ask the ESP to perform the procurement. In such cases, the material is charged back to the OEM with marginal handling fees. As such, this parameter is considered in the inputs from OEM only and not from the ESP.

KPI of hardware costs:

The total cost of prototype material and its logistics required for the ESP, are taken as a KPI. The related costs like, tooling and supplier engineering are excluded here. The reason for this is that the tooling and supplier engineering costs are often amortized over the contract period depending on the production numbers.

Thus, the relevant variable for the function of hardware costs is defined as:

$C_H \coloneqq \text{Total hardware and logistic costs, incurred at the ESP by the OEM}$

Function of hardware costs:

$$F_{CH} = C_H \tag{13}$$

4.3.2.7. Data from OEM (ID)

Similar to intangible inputs of the ESP (subsection 4.3.2.3, 4.3.2.4 & 4.3.2.5), the OEM also contributes intangibly in the total inputs used by the ESP. The OEM can provide valuable information to the ESP. E.g. 3D CAD data of COP, previous engineering results of a similar product or a product of the same family (i.e. FMEAs, test results or usage data in field). Such data helps the ESP to start from an already available base and avoid redundant work.

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[19] Off the shelf parts: are supplier components not specifically designed or engineered for a specific OEM.

The agreement on provision and utilization of such data can be made during the offer discussions, to consider the reductions of the efforts by the ESP.

KPI of data from OEM:

The indicator for the value of provided data must be objectively linked with the number of officially released documents by the OEM. This value shall be assigned by the ESP, corresponding to the efforts that might have been required to generate such data on its own.

The respective variable for the function of data from OEM is:

$V_{D,OEM} \coloneqq \text{Total value (assigned by the ESP) of documents provided by the OEM}$

Function for data from OEM:

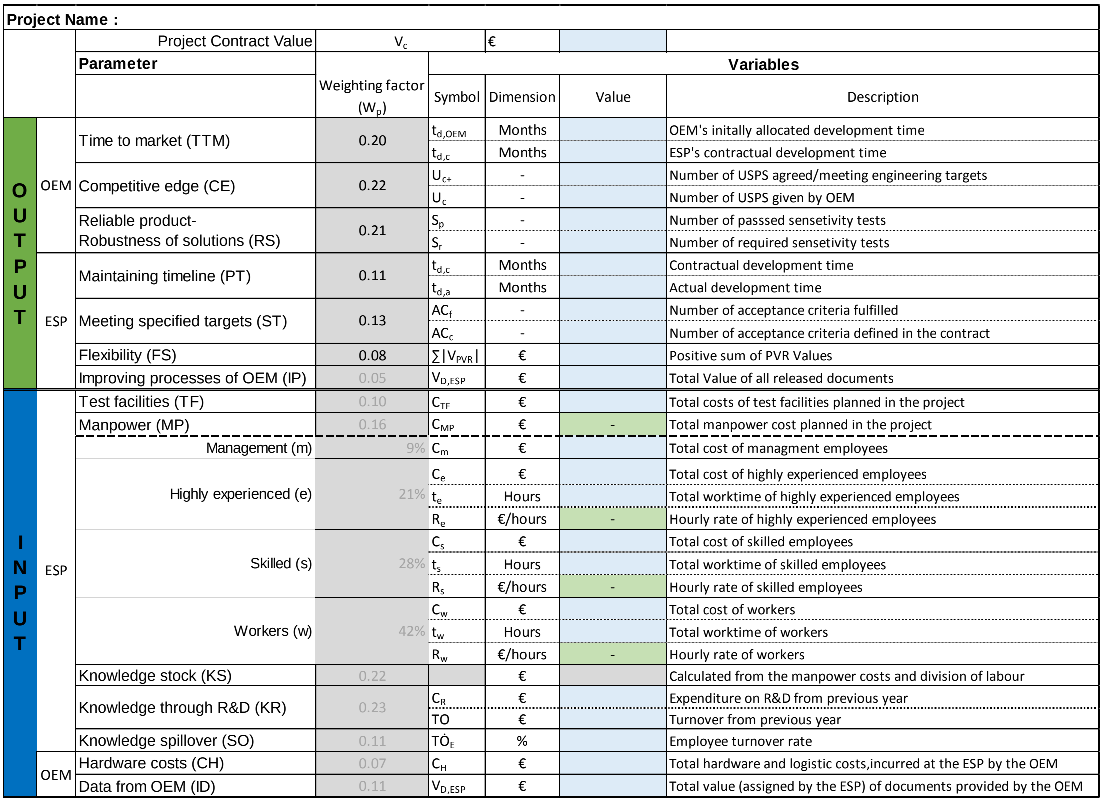
$$F_{ID} = V_{D,OEM} \tag{14}$$

4.4. Final productivity metrics

From all the output and input parameters, a MS Excel calculation metrics is prepared as the productivity method tool.

The file contains a data entry worksheet of variables as shown in Table 6 below.

Using the data from the offers as explained in subsection 4.2.3 and company information, the variables can be filled in the blue marked cells to make the calculations. Similarly for a completely executed project, the final data can be filled in to ascertain the productivity after project completion.



Project Name :							
		Project Contract Value	V_c		€		
		Parameter		**Variables**			
			Weighting factor (W_p)	Symbol	Dimension	Value	Description
OUTPUT	OEM	Time to market (TTM)	0.20	$t_{d,OEM}$	Months		OEM's initally allocated development time
				$t_{d,c}$	Months		ESP's contractual development time
		Competitive edge (CE)	0.22	U_{c+}	-		Number of USPS agreed/meeting engineering targets
				U_c	-		Number of USPS given by OEM
		Reliable product- Robustness of solutions (RS)	0.21	S_p	-		Number of passsed sensetivity tests
				S_r	-		Number of required sensetivity tests
	ESP	Maintaining timeline (PT)	0.11	$t_{d,c}$	Months		Contractual development time
				$t_{d,a}$	Months		Actual development time
		Meeting specified targets (ST)	0.13	AC_f	-		Number of acceptance criteria fulfilled
				AC_c	-		Number of acceptance criteria defined in the contract
		Flexibility (FS)	0.08	$\sum\lvert V_{PVR}\rvert$	€		Positive sum of PVR Values
		Improving processes of OEM (IP)	0.05	$V_{D,ESP}$	€		Total Value of all released documents
INPUT	ESP	Test facilities (TF)	0.10	C_{TF}	€		Total costs of test facilities planned in the project
		Manpower (MP)	0.16	C_{MP}	€	-	Total manpower cost planned in the project
		Management (m)	9%	C_m	€		Total cost of managment employees
		Highly experienced (e)	21%	C_e	€		Total cost of highly experienced employees
				t_e	Hours		Total worktime of highly experienced employees
				R_e	€/hours	-	Hourly rate of highly experienced employees
		Skilled (s)	28%	C_s	€		Total cost of skilled employees
				t_s	Hours		Total worktime of skilled employees
				R_s	€/hours	-	Hourly rate of skilled employees
		Workers (w)	42%	C_w	€		Total cost of workers
				t_w	Hours		Total worktime of workers
				R_w	€/hours	-	Hourly rate of workers
		Knowledge stock (KS)	0.22		€		Calculated from the manpower costs and division of labour
		Knowledge through R&D (KR)	0.23	C_R	€		Expenditure on R&D from previous year
				TO	€		Turnover from previous year
		Knowledge spillover (SO)	0.11	$\dot{TO}_E$	%		Employee turnover rate
	OEM	Hardware costs (CH)	0.07	C_H	€		Total hardware and logistic costs,incurred at the ESP by the OEM
		Data from OEM (ID)	0.11	$V_{D,ESP}$	€		Total value (assigned by the ESP) of documents provided by the OEM

Table 6: Table for parameter variables of productivity metrics

Table 7, below shows the worksheet of results of functions of every parameter and the final productivity.

		Paremeter	Function			
			Symbol	Value	Formula	Description
OUTPUT	OEM	Time to market (TTM)	F_{TTM}	-	$F_{TTM} = \frac{t_{d,OEM}}{t_{d,c}} \cdot W_{TTM} \cdot V_c$	[(OEM's initially allocated development time ÷ Contractual development time) x (W.f. for TTM x project contract value)]
		Competitive edge (CE)	F_{CE}	-	$F_{CE} = \frac{U_{c+}}{U_c} \cdot W_{CE} \cdot V_c$	[(Number of USPS meeting the engineering targets ÷ given number of USPS) x (W.f. for competitive edge x project contract value)]
		Reliable product-Robustness of solutions (RS)	F_{RS}	-	$F_{RS} = \frac{S_p}{S_r} \cdot W_{RS} \cdot V_c$	[(Number of sensitivity tests passed ÷ required sensitivity tests) x (W.f. for reliable product x project contract value)]
		Maintaining timeline (PT)	F_{PT}	-	$F_{PT} = \left[W_{PT} - \frac{(t_{d,a} - t_{d,c})}{t_{d,c}} \cdot W_{TTM}\right] \cdot V_c$	[W.f. for PT - (Δ actual to contractual time) ÷ contractual time x W.f. for TTM] x project contract value
		Meeting specified targets (ST)	F_{ST}	-	$F_{ST} = \frac{AC_f}{AC_c} \cdot W_{ST} \cdot V_c$	[(Number of acceptance criteria achieved ÷ Number of acceptance criteria defined in contract) x (W.f. for meeting targets x project contract value)]
		Flexibility (FS)	F_{FS}	-	$F_{FS} = \sum\lvert V_{PVR}\rvert \cdot W_{FS}$	[Positive sum of value of all PVRs x W.f. for flexibility]
		Improving processes of OEM (IP)	F_{IP}	-	$F_{IP} = V_{D,ESP}$	Total Value of all released documents by ESP
INPUT	ESP	Test facilities (TF)	F_{TF}	-	$F_{TF} = C_{TF}$	Total costs of test facilities planned in the project
		Manpower (MP)	F_{MP}	-	$F_{MP} = C_{MP} - F_{KS}$	Total manpower cost planned in the project - value of knowledge stock
		Knowledge stock (KS)	F_{KS}	-	$F_{KS} = (R_s - R_w) \cdot t_s + (R_e - R_w) \cdot t_e$	[(Δ hourly rate of skilled labour to worker x hours of skilled) + (Δ hourly rate of highly experienced to worker x hours of experienced)]
		Knowledge through R&D (KR)	F_{KR}	-	$F_{KR} = \frac{C_R}{TO} \cdot V_c$	[(R&D expenses from previous year ÷ turnover from previous year) x project contract value]
		Knowledge spillover (SO)	F_{SO}	-	$F_{SO} = T\dot{O}_E \cdot C_{MP}$	(Employee turnover rate x total manpower costs)
	OEM	Hardware costs (CH)	F_{CH}	-	$F_{CH} = C_H$	Total hardware and logistic costs,incurred at the ESP by the OEM
		Data from OEM (ID)	F_{ID}	-	$F_{ID} = V_{D,OEM}$	Total value (assigned by the ESP) of documents provided by the OEM
		PRODUCTIVITY	P_O	-	$P_O = \frac{\sum_{\text{output}} F}{\sum_{\text{input}} F}$	(Sum of output parameters ÷ sum of input parameters)

Table 7: Table of parameter functions and result for productivity metrics

4.5. Summary of method development

The development of the productivity measurement method covered both scientific preparation and data generation in industrial context.

The scientific preparation included following topics:

- Productivity parameter definition
- Definition of KPIs for these parameters
- Preparing the interview questionnaire to generate data for parameter assessment

The alignment of this preparation in industrial context involved following activities:

- Interviewing the executives
- Defining mathematical functions for the parameters
- Collection of data from some relevant offers for calculation of productivity.

One of the major tasks in the method development was finalizing the productivity parameters, their KPIs and mathematical functions.

In total seven output parameters are considered, out of which three are outputs of the OEM to create the final product for the end customer and four are outputs of the ESP for the OEM. In the output parameters of OEMs, the contribution of the ESP is taken to define the measurable variable. Three of these seven parameters have a variable, whose value can only be determined after project execution. For the evaluation of offer productivity, the value of these variables is assumed to be ‘0’ (Zero). Using the weighting factors obtained from the interviews and the project contract value, the value of the remaining four parameters can be calculated in the offer phase.

For the inputs, seven parameters are considered, out of which two are from the OEM. From the five parameters of the ESP, two are tangible with their value being clearly available from the offer calculation. The other three parameters are intangible, whose values are derived from the offer calculation and company data. The weighting factors for input parameters, obtained from the interviews are only used as reference to review the planned costs amongst the input parameters.

Finally, a MS Excel calculation file is created, to fill in the data of variables obtained from an offer and to calculate the productivity. The same calculation file can be used after the project execution to ascertain the final productivity of completed project.

5. Data analysis and discussion of findings

The data was collected in two steps for different purposes.

I. For the parameter weighting, the data was collected from the executive interviews. This data was used to define the function of output parameters in the productivity metrics and to assess the distribution of input parameters.

II. For the productivity assessment of offers, the data was obtained from projects offers of the company AVL. Using the productivity metrics, the productivity of the selected offers was calculated.

5.1. Results of interviews

As explained in subsection 4.2.2, the executives from different OEMs, as well as of the ESP (company AVL) were interviewed. Table 8 shows the results from the OEMs' perspective and Table 10 shows the ESP's perspective.

5.1.1. OEMs' perspective

		OEM1			OEM2			OEM3			OEM4			OEM5		
Parameter	**Average weightage OEM**	Weightage	Percent	Weighted percentage	Weightage	Percent	Weighted percentage	Weightage	Percent	Weighted percentage	Weightage	Percent	Weighted percentage	Weightage	Percent	Weighted percentage
OUTPUT																
Output of the OEM (contribution of ESP)																
Time to market	0.20	0.60	30%	0.180	0.70	30%	0.210	0.60	30%	0.180	0.60	20%	0.120	0.65	50%	0.325
Competitive edge	0.22		40%	0.240		35%	0.245		20%	0.120		50%	0.300		25%	0.163
Reliable product (Robustness of solutions)	0.21		30%	0.180		35%	0.245		50%	0.300		30%	0.180		25%	0.163
Output of the ESP																
Maintaining timeline	0.11	0.40	25%	0.100	0.30	30%	0.090	0.40	30%	0.120	0.40	30%	0.120	0.35	40%	0.140
Meeting specified targets	0.13		30%	0.120		50%	0.150		40%	0.160		30%	0.120		30%	0.105
Flexibility	0.08		25%	0.100		15%	0.045		30%	0.120		20%	0.080		15%	0.053
Improving processes of OEM	0.05		20%	0.080		5%	0.015		0%	0.000		20%	0.080		15%	0.053
Sum	1.00	1.0		**1.00**	1.0		**1.00**	1.0		**1.00**	1.0		**0.28**	1.0		**1.00**
INPUTS																
Test facilities	0.10	0.05			0.15			0.10			0.10			0.10		
Manpower	0.16	0.05			0.25			0.10			0.20			0.20		
Knowledge stock	0.22	0.20			0.30			0.30			0.15			0.15		
Knowledge applied through research	0.23	0.20			0.15			0.20			0.30			0.30		
Knowledge spillover	0.11	0.20			0.05			0.15			0.10			0.05		
Hardware costs	0.07	0.10			0.05			0.05			0.05			0.10		
Data from OEM	0.11	0.20			0.05			0.10			0.10			0.10		
Sum	**1.00**	1.00			1.00			1.00			1.00			1.00		

Table 8: Parameter rating from OEMs' perspective

5.1.1.1. Output parameters from the OEMs' perspective

- The OEMs rate their final output, as compared to that of the ESP, with 63:37. As discussions about priorities of the OEM's output parameters occur in the offer phase, an offer approach, meeting these priorities, can fulfill the customer-defined value.
- The three output parameters of the OEM have a similar average rating. Although the 'TTM' is lower, the reason for this may be that the OEM sees itself in the driving role to meet it. An exception to this can be observed in Asian countries, where the OEMs also use the ESP's overall PCP.
- In average, the competitive edge and the robustness of solutions are rated the same. The difference amongst the OEMs is due to their product and its market.
- None of the individual output parameters of the ESP is weighted higher than any of the OEM's output parameters. This is due to the lower rating of the ESP's overall output.
- Out of four, the two important output parameters of the ESP are meeting specified targets and maintaining timeline respectively. This indicates that the OEMs focus on the contractual agreements.
- The parameter 'flexibility' of the ESP getting an average rating of 8% of the total output (21% internal share in the output of the ESP), indicates that commitment towards this soft output during the offer phase, carries remarkable weightage in decision making to award an offer. Such a rating, which is very close to maintaining timeline (11%), reflects the ongoing dynamic trend of the market.
- The parameter 'improving processes' has different ratings amongst the OEMs. OEMs having a longer product development cycle time, have rated it higher.

5.1.1.2. Input parameters from the OEMs' perspective:

Although the distribution of input parameters is largely at the discretion of the ESP, the perspectives of the OEMs help in understanding the line of thought, which can help in alignment of resources and workforce capabilities.

- The OEMs value the knowledge part of the inputs i.e. knowledge stock, knowledge through R&D and knowledge spillover, with 56%. These intangible inputs of the ESP are more than double the tangible inputs (test facilities & manpower), which are rated with 26%.

- The OEMs expected the value of their input as ~ 18%. This is a significant portion, because by providing this value, the OEMs will expect a proportional reduction of the ESP's inputs.
- One of the OEMs' executives rated the tangible inputs of the ESP to a very low value, i.e. 10%. Although this is unrealistic, the explanation of this rating is 'It is not our business how much people you deploy in your work, we need to see the results coming from your knowledge. We know the application and you know the technology. The knowledgeable people can make the most out of this combination.' Another executive mentioned, 'If you use too many people, you will lose your profit in managing them. We will pay you only the price which we have estimated to be appropriate for outsourcing the job'.
- As mentioned in subsection 4.3.2.2, the division of manpower expected by the OEMs' executives follows a pyramid like distribution as shown in Table 9 below. These are the average values.

Manpower (MP)	**OEMs Perspective**	**ESP's Perspective**
Management (m)	*9%*	*13%*
Highly experienced (e)	*21%*	*16%*
Skilled (s)	*28%*	*39%*
Workers (w)	*42%*	*33%*

Table 9: Data for division of labor

5.1.2. ESP's perspective

As mentioned in subsection 4.2.2, the ratings from the ESP were collected to identify any gaps, which may exist in understanding the customer.

		Operations			Sales			Program Mgmt			Project Mgmt		
Parameter	**Average weightage ESP**	Weightage	Percent	Weighted percentage	Weightage	Percent	Weighted percentage	Weightage	Percent	Weighted percentage	Weightage	Percent	Weighted percentage
OUTPUT													
Output of the OEM (contribution of ESP)													
Time to market	0.32	0.70	45%	0.315	0.60	40%	0.240	0.70	50%	0.350	0.75	50%	0.375
Competitive edge	0.16		35%	0.245		20%	0.120		15%	0.105		20%	0.150
Reliable product (Robustness of solutions)	0.21		20%	0.140		40%	0.240		35%	0.245		30%	0.225
Output of the ESP													
Maintaining timeline	0.09	0.30	20%	0.060	0.40	25%	0.100	0.30	40%	0.120	0.25	35%	0.088
Meeting specified targets	0.11		40%	0.120		35%	0.140		35%	0.105		35%	0.088
Flexibility	0.07		30%	0.090		15%	0.060		20%	0.060		20%	0.050
Improving processes of OEM	0.04		10%	0.030		25%	0.100		5%	0.015		10%	0.025
Sum	1.00	1.00		1.00	1.0		1.00	1.0		1.00	1.0		1.00
INPUTS													
Test facilities	0.25	0.25			0.2			0.15			0.4		
Manpower	0.27	0.3			0.3			0.25			0.25		
Knowledge stock	0.14	0.15			0.2			0.175			0.05		
Knowledge applied through research	0.09	0.05			0.1			0.1			0.1		
Knowledge spillover	0.05	0.05			0.05			0.05			0.05		
Hardware costs	0.09	0.15			0.05			0.1			0.05		
Data from OEM	0.11	0.05			0.1			0.175			0.1		
Sum	**1.00**	1.00			1.00			1.00			1.00		

Table 10: Parameter rating from ESP's perspective

5.1.2.1. Output parameters from the ESP's perspective

- The ESP's executives rate the OEM's output as compared to their own, with 69:31. This relation is close to the OEM's estimation, which is a good basis. Probably it is cautious, but better in terms of customer orientation.
- Interestingly, the ESP's executives have rated the TTM, double the competitive edge, whereas the OEMs rated the parameters similarly. Such a rating suggests two thoughts:
  i) The ESP is not getting a complete understanding of the OEMs' methods to reach the TTM and is pessimistic about it.
  ii) The ESP values the influence of its work in providing the competitive edge to the OEMs' product, very lowly.
- The output parameters of the ESP itself are rated marginally lower than the ratings of the OEMs. However, the priorities are similar. This again indicates customer orientation.
- Amongst the ratings of the ESP's executives, there are remarkable differences. Considering the same organization, such differences may be a result of influence from recent experiences or the area of executive's responsibility.

5.1.2.2. Input parameters from the ESP's perspective:

- The most interesting finding from the interviews is the distribution of tangible and intangible resources. The ESP's executives rated the knowledge part with 28%, which is half of the perspective of the OEMs. Whereas, the tangible parameters, rated with 52%, are twice that of the OEMs. Such a highly contradicting perspective shows:

  i) Focus on capacity utilization rather than knowledge utilization
  ii) The knowledge is widely scattered and/or is becoming scarce

  This indicates an immediate problem as commented by one of the OEMs' executives, regarding the loss of profit in managing the manpower.

  As all of the executives rated the relation of tangible parameters to intangible parameters similarly, an error due to misinterpretation of questionnaire can be ruled out.

- The value of ~ 19% of the OEM's input is similar to the OEM's perspective. This again confirms a good customer orientation.
- The division of manpower suggested by the ESP's as shown in Table 9 differs that from OEMs'. The contribution of skilled labor is considered more than that of the workers. This difference to the OEMs' perspective can lead to issues of higher costs, unless the skilled labor is utilized efficiently.

5.2. Results of productivity calculations

Based on the final productivity metrics (see section 4.4), the data from projects as mentioned below, was analyzed to calculate the productivity during the offer phase.

The source data was collected through the offer calculation as explained in subsection 4.2.3, the offer text and company AVL's information.

Following projects were analyzed:

I. Project 1: High power density engine design & development for a premium car in Europe
II. Project 2: Performance & emission development, calibration and validation of an European agricultural engine to meet future US & EU emission norms

III. Project 3: Design & development of a high power non-road engine
IV. Project 4: Design & development of an engine for on-road truck application for Chinese market. The same project is also analyzed for its productivity after completion.
V. Project 5: Design & development of a 7 speed, double clutch transmission for passenger car application in Chinese market
VI. Project 6: Design & development of a dedicated hybrid car transmission for the global market

Table 11 below shows the results obtained from the productivity calculations.

Out of the above, opportunities for project #1, 2, 4 & 5 (marked green in table) are awarded by the respective OEMs to AVL. Project #3 is under a review process (marked yellow). The opportunity for project #6 is lost (marked red).

As explained in subsection 4.2.1, the weighting for input parameters given by the executives is marked in grey shade, because it is only used to compare the planned distribution of total input costs amongst the input parameters, with the expectations of the executives. For the purpose of further comparison, the weighting factor expectations from the ESP's executives are also shown in the last column.

The mix of markets, opportunity status and product was chosen to understand the differences in productivity.

To check the suitability of the method for transmission development program offers, project #5 and #6 were chosen. From the development approach, the TDP is similar to the EDP i.e. Concept phase, Generation 1 & 2 of development and Production validation phase.

		Parameter	Weighting factor from OEMs	Project1	Project2	Project3	Project4	Project4_Actual	Project5	Project6	Weighting factor from ESP
				High performance car engine	Agriculture engine emission development	High power engine	Heavy duty on road engine design & development		7 speed, car transmission	Dedicated hybrid car transmission	
OUTPUT	OEM	Time to market (TTM)	0.20	0.24	0.20	0.20	0.20	0.20	0.20	0.20	0.32
		Competitive edge (CE)	0.22	0.22	0.22	0.15	0.22	0.22	0.11	0.00	0.16
		Reliable product-Robustness of solutions (RS)	0.21	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.21
	ESP	Maintaining timeline (PT)	0.11	0.11	0.11	0.11	0.11	0.09	0.11	0.11	0.09
		Meeting specified targets (ST)	0.13	0.13	0.13	0.13	0.13	0.12	0.11	0.00	0.11
		Flexibility (FS)	0.08	0.00	0.00	0.00	0.00	0.002	0.00	0.00	0.07
		Improving processes of OEM (IP)	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
INPUT	ESP	Test facilities (TF)	0.10	0.23	0.31	0.06	0.10	0.09	0.004	0.02	0.25
		Manpower (MP)	0.16	0.36	0.43	0.59	0.57	0.58	0.58	0.66	0.27
		Management (m)	*9%*	*11%*	*20%*	*19%*	*16%*		*9%*	*12%*	*13%*
		Highly experienced (e)	*21%*	*14%*	*1%*	*11%*	*26%*		*4%*	*7%*	*16%*
		Skilled (s)	*28%*	*48%*	*40%*	*39%*	*35%*		*80%*	*66%*	*39%*
		Workers (w)	*42%*	*27%*	*39%*	*31%*	*23%*		*7%*	*15%*	*33%*
		Knowledge stock (KS)	0.22	0.09	0.07	0.19	0.19	0.18	0.20	0.17	0.14
		Knowledge through R&D (KR)	0.23	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.09
		Knowledge spillover (SO)	0.11	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.05
	OEM	Hardware costs (CH)	0.07	0.19	0.04	0.04	0.03	0.03	0.03	0.04	0.09
		Data from OEM (ID)	0.11	0.02	0.04	0.00	0.00	0.00	0.09	0.00	0.11
		PRODUCTIVITY		**61%**	**57%**	**52%**	**59%**	**61%**	**43%**	**28%**	

Table 11: Results of productivity calculation

5.2.1. Results' analysis

From the results derived through calculation of productivity, following observations are made.

5.2.1.1. Productivity results

- The opportunities of engine projects, which were won, have a productivity of ~ 59 %.
- Project #3, which is under review for its pricing, has a productivity of 52%. From the parameter analysis, there are two reasons for the lower productivity.
  - i) The output parameter of competitive edge is not completely fulfilled at the offer stage.
  - ii) The manpower costs, including knowledge stock, are the highest as compared to the other engine projects.
- Project #4 is already completed. The data after completion was updated and the analysis reveals following:
  - o The project shows an improvement in productivity after execution. The reason behind this is a partial fulfillment of output parameters like robustness of solution and flexibility.
  - o On the other hand, there is deterioration of parameters like maintaining timeline and meeting specified targets. A minor increase in manpower cost is also seen.
- Transmission project #5, which was won, results in a productivity of 43%. This is relatively low compared to the engine projects. The reason behind this is visible in the lower output of competitive edge and meeting specified targets. There is also a high level of manpower and knowledge stock used in input, along with relatively high input data from OEM.
- The lost opportunity in project #6 with just 29% productivity, indicates a problem with the low output. The reason of not getting a score on competitive edge and meeting targets was that these parameters are not defined in the offer.

5.2.1.2. Output results

- The functions for output parameters contain the weighting suggested by the OEMs' executives. As such, all the offers deliver the same values for the output parameters in case the variables are fulfilled.

- An exception to this was observed in project #6, in which the specifications and targets were not specified in the offer, leading to values of zero for the parameters competitive edge and meeting targets. As the offer opportunity was lost, it must be emphasized that the offer document must contain the customer value, irrespective of technical discussions.
- In the comparison of results from the completed project # 4, the parameter robustness of solutions could not reach maximum value. The investigation revealed that two sensitivity tests in the responsibility of the OEM were not performed. Both the ESP & OEM had forgotten to monitor the DVP. This emphasizes the necessity of clearly defining measurable deliverables in the offer document, including the responsibility.

5.2.1.3. Input results

The total input distribution amongst the parameters is analyzed to compare it with the weightings estimated by the OEMs', as well as by the ESP's executives.

- For the test facilities, the weightage of 0.10 and 0.25 was suggested by the executives of the OEMs & ESP respectively. The data however shows a wide range from 0.04 to 0.31.
    - The reason for this seems to be the type of project and/ or work share between the OEM and the ESP.
    - As seen from project #4, the test facilities cost 10% of the total input, in offer, as well as in execution was used. This would mean that for demonstrating the critical output parameters of the OEM, i.e. robustness of solutions, USPS and meeting the specified target, a focused testing effort should be part of an offer.
- The manpower weighting of 0.16 suggested by the OEMs or 0.27 by the ESP could not be realized in any offer as the analyzed values between 0.36 and 0.59 are much higher. (The lost opportunity of project # 6 is excluded here due to its failure to define customer output value). Some aspects of this high content can be explained as below.
    - The distribution for the division of labor is shown in Figure 6 below. The red horizontal bar above every division, indicates the range between OEMs' & ESP's suggestion. It can be clearly seen that the division follows neither the OEMs' nor ESP's suggestion.

- Projects # 1, 3 & 4 which are of similar type i.e. engine design and development, also do not show consistency in this distribution.
- An explanation for this was discussed with experts and multiple reasons are noted. These are:
    i) Different guidelines from skill teams for resource planning
    ii) Planning is done according to available skills rather than required skills
    iii) Inconsistency of experts involved in planning
    iv) Non-availability of structured data e.g. from database, for executed projects
    v) Insufficient central method for assessment of inputs

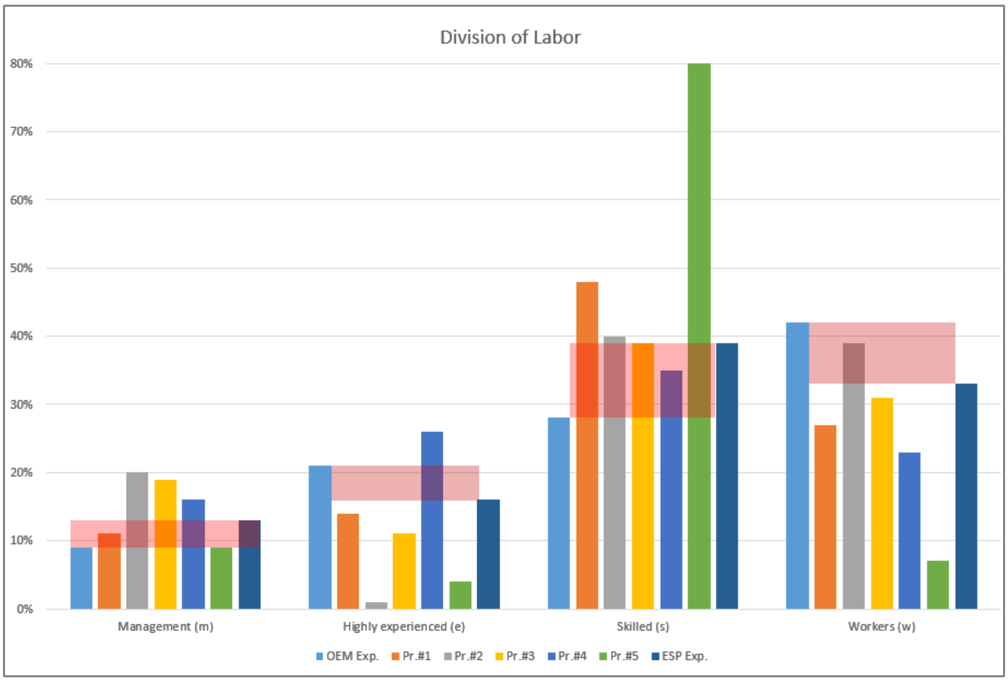


Figure 6: Division of labor in offers

- The value of knowledge stock in projects lies between the weighting of 0.22 by the OEMs and 0.14 by the ESP. For projects #1 & #2, the lower values were justified by the experts with the work content of these two projects.
- The parameter knowledge applied through research is consistently the same, as suggested by the ESP's executives. During the definition of the KPI and

function of this parameter, no other additional variable could be found that may have led to a higher value.

  - Either the image of AVL as an innovator is highly rated by the OEMs' executives, creating high expectations even as 10% turnover is spent on in house financed R&D.
  - Or the OEMs expect a high level of reuse of work and/or knowledge, performed in similar projects by the ESP.

- The value of spillover is very low. This is due to the variable employee turnover rate, which is very low in AVL (meaning high stability). This parameter was rated highly by the OEMs, probably due to their own country data.
- The value of hardware costs depend largely on the type of project and parts' procurement responsibility between the OEM & the ESP. In the project #1, this was ESP's responsibility and the value was high. There was already a feedback from the OEM, to look into this requirement during the project.
- The value of data from OEM is assigned by the ESP based on the offer text, which defines required inputs. Often there is no clear definition as to what data is mandatory and what data is just for information. Such a clear definition can help in the reuse of available input from the OEM, reducing the ESP's efforts.

5.3. Summary of data analysis

In this chapter, the data obtained from the executive interviews and from the productivity calculation has been presented and discussed.

From the data obtained in interviews, a main positive outcome was seen in the contribution of output and input of the OEM. Here, executives of both sides have a similar ratings. For two important parameters of the OEM's output, the ESP's executives were remarkably different, indicating a gap in understanding priorities.

The major difference in perspective was observed in the distribution of tangible and intangible inputs. The OEMs' executives expect a high utilization of knowledge, rather than facilities and manpower, whereas the ESP's executives intend to plan more resources. Although the input planning is the prerogative of the ESP, a huge difference may lead to difficulties in alignment of the project teams (i.e. duplication of work or missing out some tasks).

The interview results confirm the need to focusing on the customer-defined values as elaborated in subsection 2.1.1.

The productivity calculations were performed for project offers covering different products and markets. A consideration to compare won, under review and lost offer opportunities, was also given. The results show that various project opportunities can be compared based on their productivity; not just in offer phase but also after project completion.

As the output is mainly focused on the customer-defined value and priorities, the value of its parameters remains same for all offers. A deviation from the offer can be assessed for an executed project. The analysis of the lost opportunity revealed missing definition of customer values in offer. Similarly, the analysis of the executed project revealed missing focus on a customer valued parameter.

The input data analysis reflected some critical deficiencies in the planning of manpower and division of labor. The probable causes can provide many improvement measures, which is the ultimate aim of any productivity measurement.

6. Method validation and implementation topics

After the development of the productivity measurement method, the validation to ensure its acceptance was necessary. Along with this, a framework of proposals was also required to enable its implementation in order to achieve the goal of creating lean offers. These topics are covered in this chapter.

6.1. Validation of method

Through this research, the productivity measurement metrics, the parameters constituting the output & inputs and the variables which make these parameters measurable have been developed. However, validation of the method is essential for its acceptance and further usage.

This was performed as explained in following subsections.

6.1.1. Key-user feedback on methodology

While performing the method development and plausibility calculations, important feedback was received from experts from different sections of the ESP's organization. After the development of the method, the results of the analyzed projects were also discussed with these people who represent:

i) Project Planning: Responsible for creating the offers and future key-users of the method.

ii) Project Management: Responsible for correctness of offer with respect to the customer requirement. They are also responsible for the execution of projects.

iii) Sales: Responsible for bringing in the opportunities and assessing the customers' values. They represent the ESP at the OEM and decide the pricing strategy with the management.

iv) Product management: Responsible for the global strategy of the products and services.

The feedback received is grouped in three aspects as below:

Positive feedback:

- It is a simple and objective way of analyzing the offer, which will help in understanding customer requirements and providing them exactly what is required.

- This will simplify offer preparation by getting specific inputs from the customer and make it more robust.
- This is a helpful tool for the project management to get a quick overview of whether customer requirements are addressed and how the overall inputs are distributed (especially manpower).
- If the projects are planned and assessed using this method, it will help sales in explaining the considered customer value more objectively to the customer.
- It would be possible to build database and streamline offers amongst various products.
- It is interesting to see the intangible parameters, like knowledge, considered in inputs. Even the soft outputs are made measureable, which were not documented otherwise.

Cautious feedback:

- There will not be enough time to make an alignment with customer regarding the output parameters and assumptions will lead to data manipulation.
- The technical teams providing resource requirement will not understand the whole scenario and plan their resources as they are doing currently. Dealing with this situation will not be easy.
- Delays caused by the OEM will be accounted to the ESP's output.

Constructive feedback:

- It would be helpful to have functions between input and output parameters and variables, to assess if the inputs are justified.

Most of the users' feedback was positive and suggested to implement the productivity measurement method. Some of them have suggested to start the implementation for offers that have a preparation time of ~ 4 to 6 weeks.

The feedback with cautious points were considered while preparing the implementation process suggested in subsection 6.2.2. The pathway for the constructive feedback is suggested in the subsection 6.3.3.

6.1.2. Feedback about analyzed data

The data of the OEMs' interviews was discussed with the ESP's executives to present the customer view. The analyzed productivity data of the won offers was discussed with the respective project managers. Following, is the feedback:

- It was appreciated that similar distribution was estimated amongst output and inputs contributed by OEM & ESP.
- Regarding the high use of manpower and resources, rather than knowledge related parameters, some executives wondered if this is plausible and some suggested that it required proper discussions with the managers of the skill areas.
- The project managers were not surprised to see the unstructured manpower distribution in input.
- The analysis of project # 4 after its execution was appreciated. In absence of benchmark data, the result is taken as a basis. However, the improvement in productivity represents the successful completion of the project. Interestingly, there were some issues known during the production validation, which could have been revealed through sensitivity tests. The analysis indicated the missing sensitivity tests as mentioned in subsection 5.2.1.2.

6.1.3. Productivity optimization exercise

As mentioned in section 5.2, the offer for project #3 is under review with the OEM. It was decided to perform an optimization of the inputs by streamlining them to the weightings provided by OEMs' executives. The aim behind this exercise was to validate these weightings, by checking their positive impact on productivity improvement.

Table 12 below shows the results of this optimization. An improvement of 10% in productivity can be achieved by streamlining the manpower distribution. However, this improvement maintains the original project contract value for the output value. In other words, if the original productivity is kept, a reduction of 18% in contract value can be achieved.

		Parameter	**Weighting factor from OEMs**	**Project3**	**Project3_Opt**
				High power engine	High power engine
OUTPUT	OEM	Time to market (TTM)	0.20	0.20	0.20
		Competitive edge (CE)	0.22	0.15	0.15
		Reliable product-Robustness of solutions (RS)	0.21	0.00	0.00
	ESP	Maintaining timeline (PT)	0.11	0.11	0.11
		Meeting specified targets (ST)	0.13	0.13	0.13
		Flexibility (FS)	0.08	0.00	0.00
		Improving processes of OEM (IP)	0.05	0.00	0.00
INPUT	ESP	Test facilities (TF)	0.10	0.06	0.07
		Manpower (MP)	0.16	0.59	0.54
		Management (m)	*9%*	*19%*	*14%*
		Highly experienced (e)	*21%*	*11%*	*15%*
		Skilled (s)	*28%*	*39%*	*34%*
		Workers (w)	*42%*	*31%*	*37%*
		Knowledge stock (KS)	0.22	0.19	0.20
		Knowledge through R&D (KR)	0.23	0.09	0.11
		Knowledge spillover (SO)	0.11	0.03	0.03
	OEM	Hardware costs (CH)	0.07	0.04	0.05
		Data from OEM (ID)	0.11	0.00	0.00
		PRODUCTIVITY		**52%**	**62%**

Table 12: Productivity optimization example

6.2. Implementation

6.2.1. Barriers for implementation

Before defining a framework to implement the method, it is very important to think about the barriers in its implementation and find methods to remove them.

Important inputs were received from experts of the project planning team and project management, while developing the methods and data validation. Following implementation barriers are identified:

I. Organization issues (responsibility of resource planning).

II. Insufficient time during offer phase to review the input planning and rerun the optimization loop.

III. Concerns regarding the confidentiality and misuse of productivity data.

- From the three barriers that are identified, the most critical one is the organizational issue. The resource planning is done by the skill teams that have to deliver the results in the project. However, for the execution of the project, which involves the development process consisting of many workflows from different skill teams, the project management is responsible.

  For any optimization loops that may become necessary as result of the productivity analysis, a deeper analysis of the work flow and appropriate manpower may be needed. This would require the project management to make final decisions of the optimal resources. Such a situation will create a conflict of responsibilities.

  To resolve this biggest barrier, the leadership needs to find a working solution, in which the project manager coordinating the offer can make decisions without time consuming agreement processes.

- The time available to prepare an offer is the second complex barrier. In most of the cases, the opportunities are unique in terms of the product, technical targets and timeline. So understanding the customer requirements and creating an offer takes 4 – 6 weeks. A menu type offer structure, based on a standard development process is rarely usable. Yet, the OEMs demand an offer within a few days. In such a situation, analyzing the offer for productivity and performing an optimization may not be possible. The solution for such opportunities is, to tailor previously optimized offers. This however, would require a database.

- Confidentiality of the productivity data is another issue, as it is related to the competitiveness of the company. This topic has both positive and negative sides. A good productivity itself is an USP of the ESP and the OEMs shall know that their product will be efficiently developed. It is however equally important that such data is only made available to people who know the purpose of using it. It might not be necessary to provide standard access to a bigger group. The data can be made available, based on a query with proper approvals.

6.2.2. Implementation process

Having considered the barriers for implementation and probable solutions to come across them, it is important to define an approach to implement the productivity measurement method in the offer process.

The following Figure 7, shows the offer process. The green marked additions are the new blocks related to productivity measurement. The purple marked block is an update in current contents.

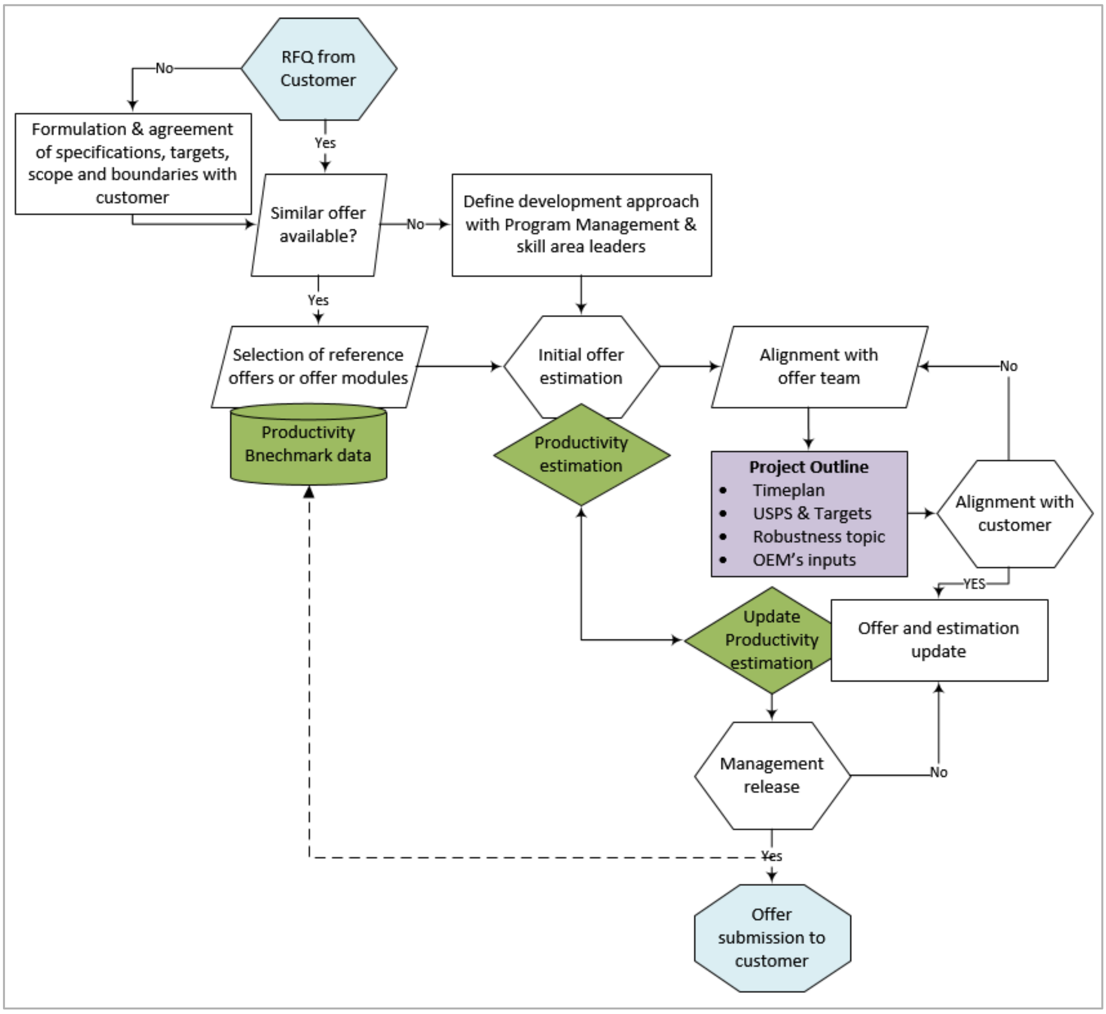


Figure 7: Integration of Productivity measurement method in the offer process

The workflow shown in the offer process is self-explanatory. The changes proposed are explained below:

- During the selection of a reference offer or modules of reference offers, the review of the productivity that was planned in the reference offers must be considered. This will enable the new proposals to start from a good reference and avoid too many optimization loops. The topic of database is covered in subsection 6.3.2.

- The productivity calculations are added at two steps.

    i) First, at the initial offer estimation. This is aimed to have a focused alignment with the offer team right from the beginning

    ii) After the alignment with the customer but prior to the offer release by the management. This is aimed to provide facts to the management to support the decision-making process.

- Specific topics from the productivity parameters are added for the alignment discussions with the customer.

With these simple additions and updates, it is expected that the productivity methodology tool will be easily integrated in the existing offer process and will not affect its duration.

6.3. Framework of proposals to achieve lean offers

One of the objectives of this research is to define proposals to achieve lean offers.

During the development of the method, executive interviews, its analysis and data analysis of the productivity calculation, some important topics were confirmed that can help in achieving the lean offer using the productivity tools.

These topics are formulated in a proposal as below.

6.3.1. Offer customer-defined values

The offer proposal must contain the customer-defined values i.e. clearly defined output parameters and their variables. These definitions must be visible in the offer document on the first or second page, immediately after the offer introduction. Such a focused presentation of outputs assists the executives and decision makers, like purchasing.

A sample structure is shown in Appendix 2. The additions to the existing offer structure are highlighted with green background.

6.3.2. Productivity database & statistical analysis

The existing database of offers should be extended with another ‘Data Table[20]’. This data table must contain the information regarding all the variables and parameters of the productivity method.

In order to assess an offer for its leanness and taking appropriate improvement steps, benchmark or reference data is required. By analyzing previous offers, as done for this research, a lot of data can be generated and statistically analyzed in a period of 2 - 3 months (Estimate ~ 100 offers).

6.3.3. Value stream mapping

During the productivity data analysis of the input parameters (see subsection 5.2.1.3), an issue was noted concerning the manpower planning. Although many reasons were assumed for this, they are not confirmed. To arrive at a systematically correct understanding of the problem and to find a solution, it is proposed to try the method of VSM.

A value stream is a “Sequence of activities required to design, produce and provide a specific good or service; along which information, materials and worth flows.” (Business Dictionary, 2017) . In every sequence or value stream, there lie value added and non-value added activities. Along with identifying the value streams, it is equally important to identify the non-value added activities.

Value Stream Mapping is a method used to document, analyze and improve the value streams. The basic idea of VSM is to look at the whole process or better said the flow of processes, from the customers’ point of view.

Apart from many advantages, the relevance of proposing this method, is that the VSM will help to identify the waste as well as its source.

This framework of proposals shall help in creating an offer, which will provide **customer-defined value** by **reducing waste** i.e. a lean offer.

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[20] Data Table: term used by MS Access for objects in a database that contain data of a particular area.

6.4. Summary of method validation & implementation

This chapter covered the validation of productivity measurement method performed by taking the feedback of key-users from various areas of organization. It also explained the validation performed by optimizing the productivity of an offer.

The chapter also discussed the implementation barriers and their possible solutions. An implementation process is defined for integrating the productivity measurement tool in the existing offer process.

Finally, a framework of proposal is explained. This framework covering the offer structure, productivity database & value stream mapping is aimed to achieve the objective of lean offers.

7. Conclusion and recommendations

This chapter completes the documentation of the research by summarizing the methodology development and its validation. The goals and requirements of the method are reviewed. The contributions of this research are discussed and recommendations for future research are proposed.

7.1. Summary of research

In the absence of appropriate measurement methods for productivity, discussions of its improvement and making lean offers is limited to theory and interpretations. It is an established fact that for a measurable project performance and continuous improvement, the measurement of productivity is a key element. The search for literature and publications revealed that unlike OEMs, ESPs do not have established methods for the measurement of productivity.

This research aimed to develop a method for measuring the productivity of engineering services. This was achieved with a synchronized combination of scientific information and its application in the context of automotive industry, as illustrated in *Figure 4*.

Following the first principle of lean, the customer and the customer-defined values were kept in focus. As such, while defining the ‘output’ of the offer, the output of the OEM to its end customer was also considered in the parameters. Similarly, for defining the functions to measure these parameters, only the weightings from the OEMs’ executives were considered. In the determining factor for productivity, i.e. ‘input’, the contributions of the ESP’s intangible parameters as well as the contribution from the OEM were incorporated.

The results from the analysis performed on some offers demonstrated that the resulting productivity values, represent the ‘Won or Lost’ status of those offers. In addition to this, the analysis also highlighted the issues of distribution amongst the input parameters. This kind of information is highly important for the management to take productivity improvement measures. As such, it can be stated that the method is suitable for the productivity measurement of an automotive ESP.

At the same time though, it is important to mention that the method is at a preliminary stage. As suggested in the implementation process, its integration in the offer process will reveal further improvement potentials.

Finally, to achieve the sustainable objective of lean offers, the proposed framework covering the offer structure, productivity database & value stream mapping need to be implemented.

7.2. Review of goals and requirements of the method

As detailed in chapter 3, following goals, which were expected to be achieved by the method, can be stated as achieved.

- Objective assessment of the offer for it productiveness → the productivity metrics (see section 4.4) makes it possible to perform the productivity analysis of an offer.
- Enable data generation for benchmarking → the values for the variables and functions of the productivity parameters will provide a base for benchmark comparison and gap analysis of offers.
- Enable productivity comparison of a project between offer phase & after completion → as the parameters contain variables from the offer phase as well as from the project completion, objective data will be available for future planning based on the lessons learned.

While developing the method, the requirements as defined in chapter 3, were always kept in focus. After the review of the analyzed data and its validation, it can be stated that these requirements are completely fulfilled. The method is:

- Easy to integrate in the offer process (see sub-section 6.2.2)
- The customer-defined values are considered in the output parameters.
- Apart from the tangible parameters, the intangible inputs of both ESP and OEM are included.
- All the variables are objectively available from the offer data, project data or company data.
- The method is not limited to the EDP, as demonstrated by the data analysis and can be used with various product development processes.

7.3. Research contribution

The method developed as the main result of this research, is an attempt to fill the vacuum in the automotive engineering service sector regarding productivity measurement. Its major contribution lies in the following areas:

I. In the thorough definition of parameters that contribute to the productivity of automotive ESPs and in suggesting the KPIs to make them measurable (especially the intangible parameters).

II. In defining the variables and mathematical functions to arrive at a metrics that enables the calculation of the productivity. This can be applied in the offer phase, as well as after project completion.

A focus on the customer-defined value will lead the results in the direction of lean development. This consideration adds value to the method as well as this research.

As elaborated in various sections, this paper acknowledges the difficulty in defining variables, which make the intangible parameters measurable. While all possible attempts and discussions were made to avoid any bias, it is presently not possible to assess it. Based on the validation done during this project, it can be stated that the research provides an important step in the direction of measuring productivity of engineering services.

7.4. Recommendations for future research

From the framework of proposals mentioned in section 6.3, a good start can be made in assessing the offers for their leanness.

During the productivity data analysis of the input parameters (see subsection 5.2.1.3), an issue was noted concerning the manpower planning. This issue can be analyzed more systematically and scientifically, by using the method of VSM. Although VSM is an established method in the manufacturing sector, its application in the automotive engineering service sector, linked with productivity improvement, could be a good topic for future research.

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List of Figures / Tables

Appendices

Appendix 1 – Interview questionnaire.

OUTPUT Parameters

#	Parameter	Weighting*	Sub Parameters/ Details
1	Output of the OEM		The degree of usefulness of ESP's output in producing goods for end customers, viz. 1. Time to market → . 2. Competitive edge → . 3. Reliable Product/ Robustness of solutions → . *(Please enter your expected share of each to make these 100%)*
2	Output of the ESP		1. Maintaining timeline → . 2. Reaching specified targets excl. legislation → . 3. Flexibility to find alternative solutions → . 4. Improvement in further processes of OEM → . *(Please enter your expected share of each to make these 100%)*

*****: Give the weightage for all parameters to make a sum of '1'

Table 13: Questionnaire for output parameters

INPUT Parameters

#	Parameter	Weighting*	Sub Parameters/ Details
1	Manpower		Here the distribution of expertise level in 4 categories is suggested. 1. Managerial → . 2. Highly experienced → . 3. Good knowledge in defined skill → . 4. Workers→ . *(Please enter your expected share of each to make these 100%)*
2	Test facilities		Facilities used, which are tangibly measureable

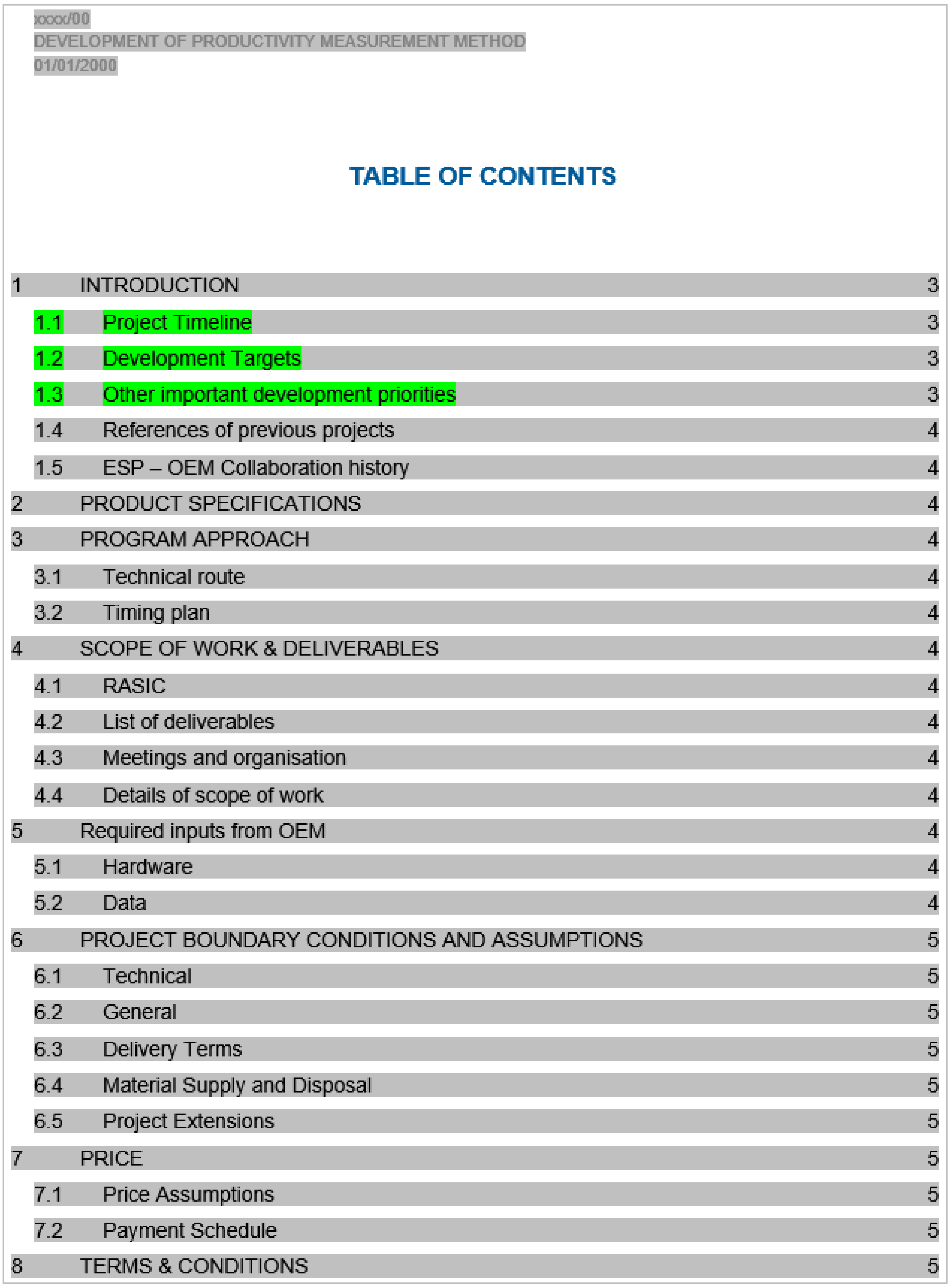
3	Knowledge stock		This is experience of people who have performed similar jobs in past reducing learning curve.
4	Knowledge applied through R&D		The ESP has established innovative solutions through own R&D
5	Knowledge spillover		Movement of employees in & out of ESP’s organization.
6	HW input from OEM		Prototypes/ carryover parts acc. to specifications from OEM usable by ESP for development
7	Know-how Input (Data) from OEM		OEM’s input to provide product and application specific data, which can be used to derive solutions

*****: Give the weighting for all parameters to make a sum of ‘1’

Table 14: Questionnaire for input parameters

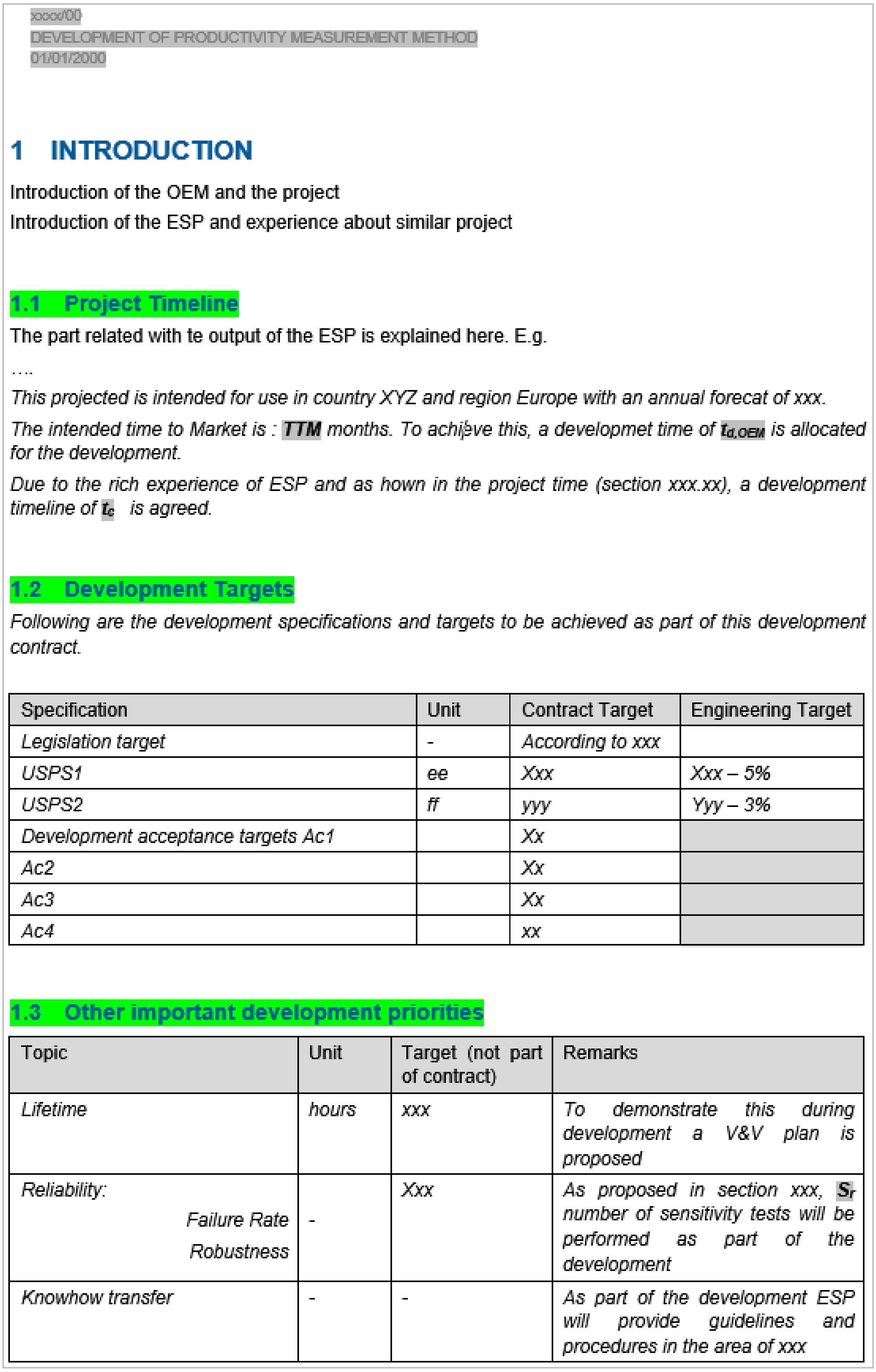
Appendix 2 – Sample offer structure

The following screen shots shows the proposed changes in the offer structure as mentioned in sub section 6.3.1. The green marked additions are made to cover the customer-defined values for the output of an offer.



xxxx/00
DEVELOPMENT OF PRODUCTIVITY MEASUREMENT METHOD
01/01/2000

TABLE OF CONTENTS



xxxx/00
DEVELOPMENT OF PRODUCTIVITY MEASUREMENT METHOD
01/01/2000

1 INTRODUCTION

Introduction of the OEM and the project

Introduction of the ESP and experience about similar project

1.1 Project Timeline

The part related with te output of the ESP is explained here. E.g.

….

This projected is intended for use in country XYZ and region Europe with an annual forecat of xxx.

The intended time to Market is : ***TTM*** *months. To achieve this, a developmet time of* $t_{d,OEM}$ *is allocated for the development.*

Due to the rich experience of ESP and as hown in the project time (section xxx.xx), a development timeline of t_c *is agreed.*

1.2 Development Targets

Following are the development specifications and targets to be achieved as part of this development contract.

Specification	Unit	Contract Target	Engineering Target
Legislation target	-	*According to xxx*	
USPS1	*ee*	*Xxx*	*Xxx – 5%*
USPS2	*ff*	*yyy*	*Yyy – 3%*
Development acceptance targets Ac1		*Xx*	
Ac2		*Xx*	
Ac3		*Xx*	
Ac4		*xx*	

1.3 Other important development priorities

Topic	Unit	Target (not part of contract)	Remarks
Lifetime	*hours*	*xxx*	*To demonstrate this during development a V&V plan is proposed*
Reliability: *Failure Rate* *Robustness*	-	*Xxx*	*As proposed in section xxx,* S_r *number of sensitivity tests will be performed as part of the development*
Knowhow transfer	-	-	*As part of the development ESP will provide guidelines and procedures in the area of xxx*