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An Empirical Study on Project Control: Applying Earned Value Management and Risk Monitoring at Fraunhofer EMFT

Von

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Executive Summary

Project Control within the Framework of Earned Value Management (EVM) plays a central role in the supply of information critical to the success of a project. The principle goal of this thesis is the application of the EVM Framework to funded projects of research organizations such as the Fraunhofer EMFT. The key focus point being the implementation procedure of this approach and current Project Management procedural changes that would need to be undertaken to facilitate clear benefits from this study i.e. the custom specific implementation of the EVM Framework to the Fraunhofer EMFT use-case. The implementation methodology uses historic Fraunhofer EMFT project data at its foundation, which has been drawn from over 150 projects over a time period of six years (i.e. from 2014 to 2020) ranging from quoted budgets of twenty-five thousand euros up to five million euros. The main criteria for success is to support the project managers by facilitating and monitoring the progress of the projects qualitatively and in parallel quantitatively demonstrating and detecting deviations from the initial project plan. Thus, promoting corrective iterations during the course of the project's lifespan.

In addition, the study will be used to succinctly forecast the outcomes of selected projects (via a VLOOKUP-function) based on the project phase and a deterministic weighted Scenario plot. The forecasting is enabled using EVM Metrics and Indices, supported by a multiple parameter Monte Carlo simulation. Key parameters will also be identified which deliver maximum impact on the future projected outcomes of the Monte Carlo simulation.

Finally, the results will be discussed, and concrete recommendations provided for improving project management at the Fraunhofer EMFT.

Restricted Notice

Table of Contents

List of Abbreviations

AC	Actual Cost
ACWP	Actual Cost of Work Planned
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
C/SPCS	Cost/Schedule Planning Control Specification
CPI	Cost Performance Index
CPM	Critical Path Method
DHS	Department of Homeland Security
DIN	Deutsche Industrie Norm
DoD	Department of Defence
DoE	Department of Energy
DOT	Department of Transportation
e.V.	Eingetragener Verein
EAC	Estimate at Completion
EIA	Electronic Industries Alliance
EMFT	Einrichtung für Mikrosysteme und Festkörper Technologie
ERP	Enterprise Resource Planning
ETC	Estimate to Completion
EU	European Union
EVM	Earned Value Management
EVMS	Earned Value Management System

EVMSC	Earned Value Management Systems Criteria
FAA	Federal Aviation Administration
FOM	Fachhoschule für Ökonomie and Management
HHS	Health and Human Services
HQ	Headquarter
ITM	Integral Total Management
KPMG	Klynveld Peat Marwick Goerdeler
NASA	National Aeronautics and Space Administration
OBS	Organizational Breakdown Structure
PERT	Program Evaluation and Review Technique
PMB	Performance Measurement Baseline
PMBOK	Project Management Book of Knowledge
PV	Planned Value
R&D	Research and development
SPI	Schedule Performance Index
SV	Schedule Variance
TCPI	To-Complete Performance Index
USAF	United States Air Force
WBS	Work Breakdown Structure

List of Figures

List of Tables

1 Introduction

Given the current business environment, wherein organizations are confronted with high competition, scarce resources, increasing costs and fluctuations in global market conditions, organizations are forced to respond to these challenges by implementing efficient management tools that will address shortcomings in the managerial procedures and offer alternative methods of approach. Thus, equipping management boards to take clearer decisions that will enhance their business activities and increase their overall performance.

According to the 2019 pulse survey issued by the Project Management Institute (Project Management Institute, 2019):

"*Data from the new 2019 Pulse survey show organizations wasted almost 12 percent of their investment in project spend last year due to poor performance—a number that's barely budged over the past five years. It's time to add a new ingredient to that old formula, especially given the fundamental shift in how work is getting done. Few jobs of the future will revolve around a bulleted list of static responsibilities. More and more, people in all roles will be hired to manage a portfolio of projects, and increasingly, those projects will be tied to technology.*" (Project Management Institute, 2019, p. 2)

It is against this background that I took the decision to perform a research into this topic in connection with my thesis. In my occupation as a Project Controller within a large Research and development organization such as Fraunhofer, I am faced with challenges on a regular basis. Fraunhofer EMFT receives product- and service-related contracts in the form of projects from various organizations all over the world. This calls for stringent Project Management procedures in order to address the above mentioned challenges, deliver maximum customer satisfaction and strengthen customer retainment.

This thesis intends to shed light on the role that Project Control has played and continues to play during the lifespan of the various projects acquired at Fraunhofer EMFT from 2014 to 2020. The tool used for undertaking this research is referred to as Earned Value Management. With the application of the EVM metrics and indices, deviations from budgeted work packages are identified during the project lifespan and corrective measures proposed. In addition, I also address the risk component inherent in projects as work is performed by applying a multi-parameter Monte Carlo simulation, Scenario- and Sensitivity-Analysis in order to stem the risk and provide project managers with current information that will strengthen the decision making process. My focus in the literature review revolves around EVM and its implementation within the project environment at Fraunhofer EMFT. Thus, displaying the risk involved during the project lifecycle and proposing corrective measures. This thesis is further sub-divided into ten chapters which are as follows:

Following the introduction, Chapter Two gives an insight into Project Control at Fraunhofer EMFT. This chapter begins with an overview of the various types of Research and development projects that are managed at Fraunhofer EMFT with regards to Project Control. It further depicts the different areas of expertise offered by the Institute to enlighten the reader about the various fields in which the Institute operates. It then provides an insight into the application of Project Management procedures to meet the various project requirements. On a final note, this chapter highlights the requirements necessary for EVM to be established at Fraunhofer EMFT.

Chapter Three enlightens the reader about the literature research conducted in order to gain an understanding about the topic which serves as a base for the Framework of this thesis. It begins with an overview of Earned Value Management and its underlying tools to measure and forecast possible events that may occur during the lifespan of the projects. It then compares EVM to alternative measurement techniques and explains the reason why EVM is chosen as the methodology for this Framework. Furthermore, this chapter conducts literature research into the application of Project Control and monitoring procedures within the EVM context and how it can enhance the control and monitoring of projects at Fraunhofer EMFT. Also, it enlightens the reader about the costing system currently applied at Fraunhofer-Gesellschaft. On a final note, this chapter provides and implements three Analysis tools for monitoring the development of risk components during project duration at Fraunhofer EMFT.

Chapter Four reveals detailed information on the application of EVM across the population of 150 projects at Fraunhofer EMFT, which is used for conducting this research. This chapter starts with an overview of the project data collected before moving on to the application of EVM metrics and indices as well as forecasting indices. It then gives insight into the implementation of the Scenario and Sensitivity Analysis and finally the use of Monte Carlo simulations to provide confident assertions about the level of risk embedded at the various phases of the projects.

Chapter Five discusses the results derived from the application of the EVM tool and then evaluates the results derived from the Scenario and Sensitivity Analysis before evaluating the results of the Monte Carlo Analysis. Also, a critical Analysis of the results and evaluations is conducted and their implications on the project outcomes.

Chapter Six provides a comprehensive conclusion based on the research conducted within the Framework of this thesis. This includes a summary, contribution and limitations of the research Framework before finally recommending improvements for conducting Project Control at Fraunhofer EMFT.

Chapters Seven, Eight and Nine serve as complementary reference points to the Framework of this research in order to give the reader an understanding of the structure implemented during the conduction of the research. This includes a detailed time schedule, appendixes and a bibliography related to the Framework of the research.

Chapter Ten provides a mandatory Integral Total Management (ITM) checklist which delivers a 360° entrepreneurial view developed by FOM to guide the author through the complex interrelationships between the various disciplines and decision-making fields of business administration.

1.1 Motivation

This subchapter delivers three factors that motivated me to undertake the research conducted in this master thesis. On a first note, in my occupation as a Project Controller at a Research and development organization such as Fraunhofer EMFT, I experience challenges in monitoring the current status of certain projects at any given time. Be it related to the project scope, work already performed or events that might impact the future of the project. Even though, the management at Fraunhofer EMFT conducts monthly reviews, uses Excel spreadsheets and a Fraunhofer internal ERP software referred to as Sigma, wherein project managers and heads of departments deliver regular feedback, the Institute is still faced with emerging challenges that often render preemptive measures as late. I believe that with the application of Earned Value Management and corresponding risk Analysis tools such as the Sensitivity and Scenario Analysis backed by Monte Carlo evaluations, the Institute would be in a position to manage its projects added efficiently and create a conducive working environment with regards to Project Management. Secondly, after conducting an extensive research into the application of Earned Value Management, my findings support my motive in that Earned Value Management is a standardized Project Management tool for measuring the work performance in its projects. Thirdly, given that Fraunhofer EMFT already has an intact Project Management system in place, a conducive environment for the application of Earned Value Management and Risk monitoring tools as mentioned above can contribute in ensuring that the work performance in projects are displayed at regular intervals empowering project managers to take corrective measures in a timely manner when necessary and thus, secure the success of projects.

1.2 Description of Problem

The Monitoring of Projects at a Research and development Facility such as Fraunhofer EMFT requires an extensive input of Project Control procedures in order to properly manage the sustainability of projects and avoid the growth of inconsistencies that may emerge during the lifespan of the projects. In this regard, Fraunhofer EMFT requires an integrative Project Control process in conjunction with its Project Management system that measures the work performance, predicts final costs and project duration against the planned or budgeted values that have been initially calculated before the begin of the project. Also, Fraunhofer EMFT requires tools that can identify emerging problems before they become critical and give the project managers the upper hand to take advantage of the opportunities during the course duration of the project. The Monitoring of Projects also includes a risk Analysis with respect to time, cost and scope of the project. Fraunhofer EMFT requires an integrative risk measuring approach that will enhance the efficiency of the project plan and deliver maximum results that ultimately leads to customer satisfaction and retainment. With the support of Sensitivity, Scenario and Monte Carlo evaluations, project managers at the Institute would be a in better position to take confident decisions about the course of plan for their respective projects.

1.3 Objective of Research

This research was performed on a total number of 150 funded research projects with varying types of funding character acquired by Fraunhofer EMFT during the period ranging between 2014 and 2020. The quoted budgets of the research projects range between twenty-five thousand euros and five million euros.

The main objective of this research is to empirically investigate the effectiveness of the Project Control procedure at Fraunhofer EMFT based on the project population mentioned above and apply a different approach in order to enhance the Project Control procedure at the Institute. This thesis thereby applies the Earned Value Management tool in order to provide the management at Fraunhofer EMFT a strategic alternative plan on how to efficiently monitor the sequence of projects and develop counteractive measures in advance where necessary. This thesis also focuses on Project Control measures as well as propose project risk monitoring tools in order to highlight potential risk factors affecting the success of the project and increase the general awareness of project managers towards the planning and scheduling of projects as a whole.

1.4 Methodology of Research

This thesis is based on a quantitative empirical research which is applied on acquired projects in a research and development organization. The research methodology for this thesis considered several critical factors including the population size of the samples selected, an appropriate approach for gathering the primary data embedded in the population of samples and the application of MS Excel to analyze the data. Also, it is important to note that the limitations experienced during the data gathering process will also be mentioned later in the thesis and explanations given on how they were maneuvered.

In order for the research to be conducted, the primary data of the projects had to be retrieved from the Fraunhofer ERP software and entered into an Excel spreadsheet accordingly. The Framework created for the entry of the primary data of the projects is as follows:

Firstly, basic information about the respective projects are collected. This includes the project title (in a coded form due to non-disclosure agreements between Fraunhofer-Gesellschaft and the respective contracting entities), approved budgets and the types of funding administered to the projects – which are depicted as follows:

Table 1: Types of Funding existing at Fraunhofer EMFT

Types of Funding	Description
Base (HQ)	Fraunhofer Headquarters Funded projects
Base (Institute)	Projects funded internally by Institute
EU + Base	Joint Funding EU and Institute
EU + Federal	Joint Funding EU and Federal
EU + Federal + Base	Joint Funding EU, Federal and Institute
Federal	Federal funding
Federal + Industry	Joint Funding Federal and Industry
Industry (Local)	Local Industry Funding
Industry (EU)	Funding by Industry sector in EU
Industry (International)	Funding by Industry sector International
State + Base (Institute)	Joint Funding State and Institute
Other + Base (Institute)	Joint Funding University and Institute

Source: Self-Created in accordance with the Fraunhofer funding scheme

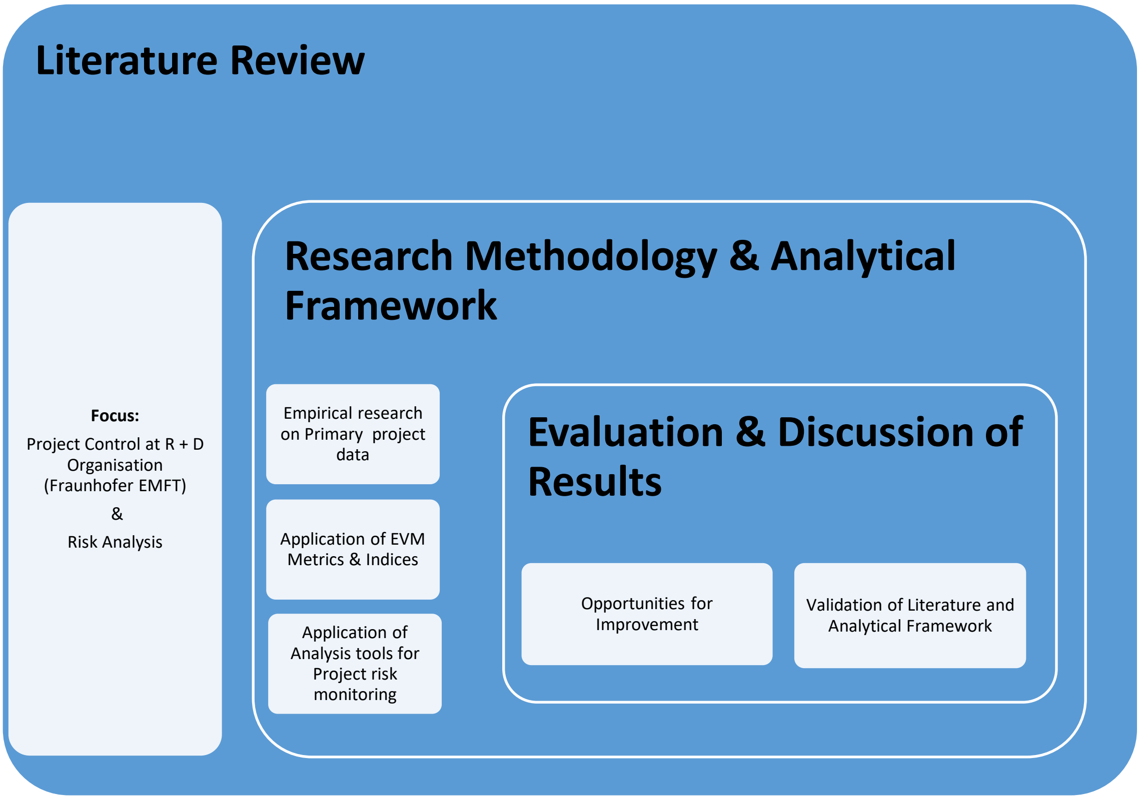
Secondly, the planned durations are compared to the real time durations of the projects and the respective variances in durations recorded.

The Framework then proceeds to the planned or budgeted costs including Man hours calculated before project acquisition and compares those values to the costs incurred during the sequence of the project before finally depicting all variances in the costs as they occurred.

1.5 Structure of Work

Figure 1 below depicts a holistic view of the structure of this thesis. Chapter two gives a detailed insight into the R&D structure of Fraunhofer EMFT in which it provides an overview of the R&D projects at the Institute as well as the areas of expertise and the Project Management process including Project Control and Monitoring. The Literature review in chapter three forms the theoretical Framework of this thesis. Starting with an overview of Earned Value Management, including the background of this tool and its performance measuring techniques before stating the requirements necessary for EVM to work at Fraunhofer EMFT. The chapter then proceeds to a comparison of EVM to alternative performance measuring techniques and a justification for using EVM. Furthermore, the chapter sheds some light into the costing system at Fraunhofer EMFT. Chapter three finally looks at three Analysis tools that are applied in this thesis for project risk monitoring purposes. The quantitative empirical research applied on the project population is anchored in chapter four of this thesis, in which, an overview of the project data is provided, the application of EVM and implementation of the Scenario-, Sensitivity-, and Monte Carlo Analysis thereof. Chapter five discusses and critically analyzes the results derived from chapter four after which, the implications of those evaluations on project outcomes are highlighted. Chapter six presents the conclusion of the research performed and delivers recommendations for the improvement of Project Control at Fraunhofer EMFT. Chapter Seven shows an overview of the thesis timeframe including a Gantt chart.

Figure 1: Structure of Thesis



Source: Self-Created

2 Project Control at Fraunhofer EMFT

The aim of this thesis is to contribute to the enhancement of the Project Control procedure at Fraunhofer EMFT by applying the Earned Value Management tool and introducing methods on how to minimize the risk component inherent in acquired projects by means of the Scenario- and Sensitivity-Analysis backed by Monte Carlo simulations.

Project Control is embedded in the Project Management standard at Fraunhofer EMFT in accordance with the DIN 69901-5 bullet point 3.54 (Deutsche Institut für Normung e.V., 2009, p. 12), which in other words describes Project Control as:

"*Project Controls are the data gathering, data management and analytical processes used to predict, understand and constructively influence the time and cost outcomes of a* *project or programme; through the communication of information in formats that assist effective management and decision making*" (Project Controls online.com, 2019).

The Project Management standard at Fraunhofer EMFT is based on the Project Management Body of Knowledge (PMBOK) standards offered as a form of guidance by the Fraunhofer-Gesellschaft to facilitate the Project Management processes at the various Institutes. (Fraunhofer-Gesellschaft e.V., 2017).

The PMBOK on the other hand is a standard developed by the Project Management Institute (PMI) in which detailed descriptions are presented for the application of methods, processes, techniques and tools in order to manage projects successfully (Project Management Institute, 2013).

The Project Management Institute set 47 Project Management processes into the Project Management Body of Knowledge of which 11 processes focus on the Monitoring and Controlling processes within projects. Table 1 below shows these 11 Monitoring and Controlling processes with a short description of their functions.

Table 2: The 11 Monitoring & Controlling processes

Steps	**Process**	**Description**
1	Monitor and Control project work	performance objectives defined in the Project Management plan are progressively Tracked, reviewed and reported to the project leader
2	Perform integrated change control	All requests for changes or modifications to project documents, deliverables, baselines or Project Management plan are carefully reviewed before approval or rejection
3	Validate Scope	Acceptance of all completed project deliverables are formalized

4	Control Scope	Continuous monitoring of the status of the project and product or service scope and managing all change affecting the scope baseline
5	Control Schedule	Continuous monitoring of the status of the project activities to update the progress in the project and managing all changes in the schedule baseline in order to achieve the project plan
6	Control Costs	Continuous monitoring of the status of the project to update the project costs and manage all changes to the cost baseline
7	Control Quality	Monitoring and recording of results of executing the quality activities in order to assess the project performance propose necessary change recommendations
8	Control Communications	Meeting project stakeholder expectations by continuously Monitoring and Controlling communications throughout the project lifecycle
9	Control Risks	Implementing risk response plans, tracking identified risks, monitoring residual risks, identifying emerging risks and evaluating the effectiveness of risk processes during the project lifecycle
10	Management of Procurement	Management of procurement relationships, monitoring of contract performance and applying amendments to contracts where necessary
11	Control stakeholder engagement	Engaging stakeholders by monitoring project stakeholder relationships and adjusting strategies and plans accordingly

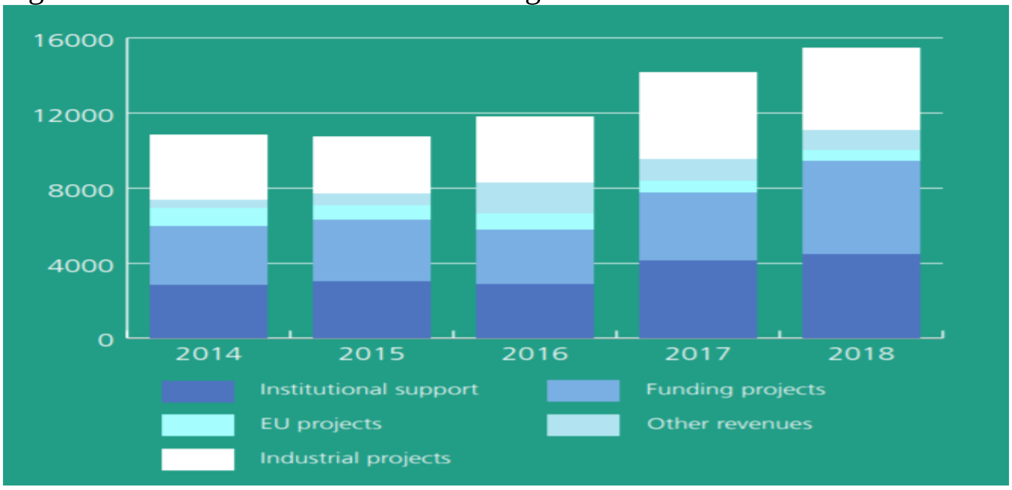
Source: *(Project Management Institute, 2013, p. 451)*

The following subchapters enlightens the reader about the capacity of the Institute and the role it plays in the Research and development landscape.

2.1 Overview of R&D Projects

Since 1974 Fraunhofer EMFT has operated in a wide array of Research and development projects focusing on the Research and development of Microsystems and solid state Technologies. In 2018 its total budget amounted to 15.5 million euros with contracts from the Industrial sector summing up to approximately 4.5 million euros, accounting for 30.7 % of total volume. In total Fraunhofer executed 105 projects alone in 2018. The Figure 2 below gives an illustration of Fraunhofer EMFT's annual performances in the R&D project landscape ranging from 2014 to 2018.

Figure 2: Fraunhofer EMFT Annual Budgets 2014 – 2018



Source: (Fraunhofer EMFT, 2019b, p. 10)

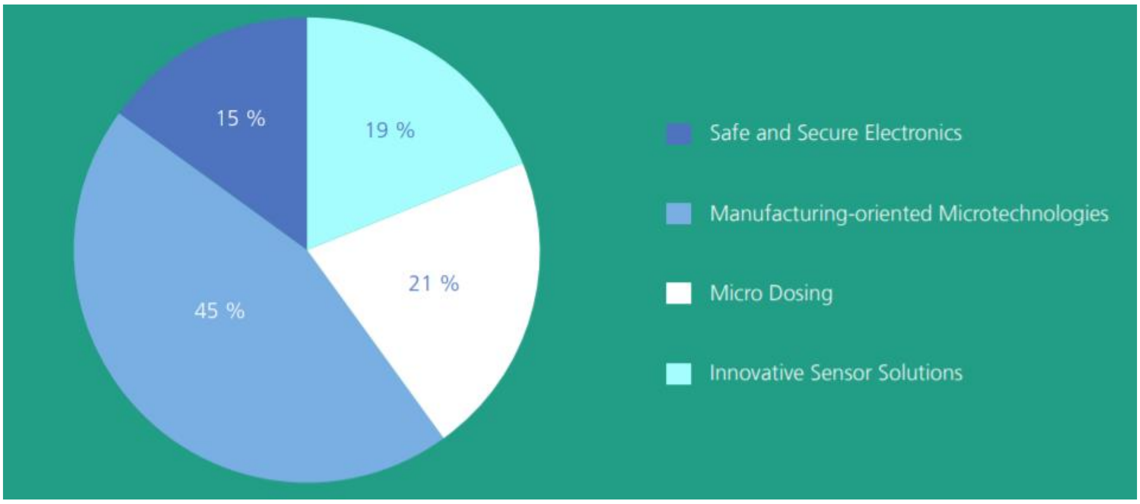
As depicted in the illustration above the Research and development projects at Fraunhofer EMFT consist of the following types of projects:

- **Institutional Support Projects:** these projects serve to develop, implement and optimize processes, products and equipments until they become matured for application and the market
- **EU Projects:** these projects are usually collaborative in nature. Wherein, the European Framework Programme for Research and Innovation, referred to as Horizon 2020 initiates and funds global Companies, Universities and Institutes to form consortial partnerships and promote innovative ideas

- **Industrial Projects:** these are contract-based projects wherein, industrial companies charter Fraunhofer EMFT for specific industry-related R&D undertakings
- **Funding Projects:** these projects are usually national or state funded programmes in nature which also promote Federal or Regional innovative research topics
- **Other Projects:** these include projects based on contracts wherein the Institute receives royalties for IP-related Research and Innovations

As one can gather, it is the broad portfolio of projects that gives Fraunhofer EMFT the standing to establish itself and create an innovative frontier within the Research and development landscape. In addition, Figure 3 shows the distribution of projects according to the areas of expertise offered by Fraunhofer EMFT in 2018

Figure 3: Distribution of projects to the areas of expertise



Source: *(Fraunhofer EMFT, 2019b, p. 10)*

Figure 3 shows how Fraunhofer EMFT implements its broad project portfolio management across its areas of expertise.

2.2 Areas of Expertise

Fraunhofer EMFT has four main areas of expertise which is depicted in Figure 4. These four main areas of expertise build up the strategic business-development mindset of the Institute. All projects acquired by Fraunhofer EMFT are in one way or the other linked to either one or a combination of these areas of Expertise. They consist namely of the Manufacturing-oriented Microtechnologies, which lays the foundation for the other three areas: Innovative sensor solutions, Safe and Secure Electronics and Micro Dosing. These four areas of expertise interact with each other in order to provide sustainable solutions that generate added value for the society and economy as a whole.

Figure 4: Fraunhofer EMFT Areas of Expertise

Source: *(Fraunhofer EMFT, 2019a)*

The Research and development activities at Fraunhofer EMFT applies its areas of expertise to focus on areas of specialty such as energy-efficient sensors, sensors on flexible substrates, flow sensorics, chemical & gas sensorics, bio sensorics, cell-based sensorics, characterization and validation as well as combined sensor systems (Fraunhofer EMFT, 2019a, p. 14). The following bullet points render a brief insight into the four areas of expertise at Fraunhofer EMFT (Fraunhofer EMFT, 2019b, pp. 14–17):

- **Innovative Sensor Solutions:** One research focus at Fraunhofer EMFT is innovative sensor solutions that can be individually tailored to our customers' needs and requirements. With their broad technological expertise, Fraunhofer EMFT scientists develop novel, high-performance sensors, design robust, secure and fast sensor networks and create system solutions that enable the sensors to interact perfectly with their environment. In this area, in-house developments are sometimes combined with existing solutions.

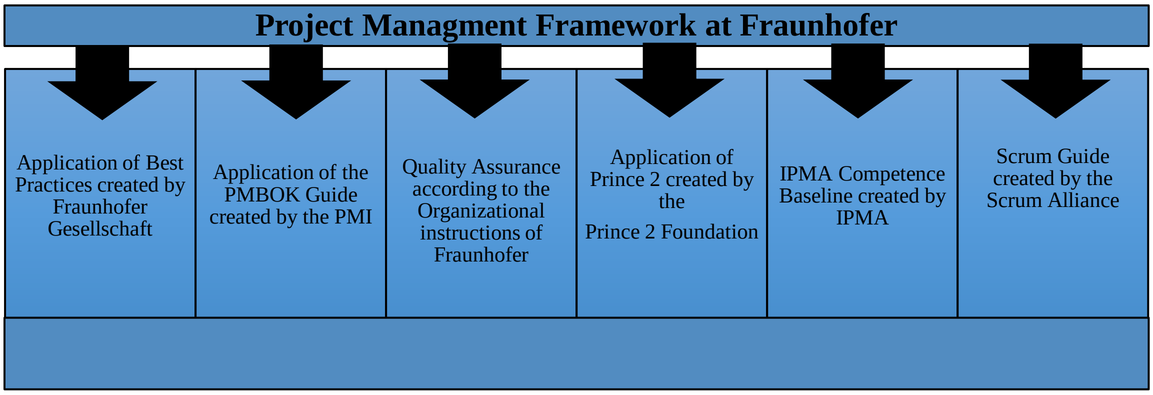
- **Micro Dosing:** Piezo-electrically powered micropumps are at the heart of these micro dosing systems. The Fraunhofer EMFT team possesses extensive expertise and practical experience in the design of micropumps. On this basis, it is able to adapt the technological parameters in terms of dosage precision, counter-pressure resistance, size, energy consumption, particle resistance, bubble tolerance and free-flow protection to the requirements in question. Fraunhofer EMFT has designed a portfolio of silicon and stainless steel/titanium micropumps for the various areas of use. One main focus of R&D activities in the area of silicon micropumps is further miniaturization.
- **Safe and Secure Electronics:** Internet of Things, Industry 4.0, Big Data – there is no question that digitalization has come to play a role in virtually all areas of our day-to-day lives. Safe and secure electronic systems are required as the “infrastructure” of this interconnected world.
- **Manufacturing-oriented Microtechnologies:** Fraunhofer EMFT is equipped with extensive cutting-edge technological facilities in the area of microelectronics and microtechnology that are maintained by experienced researchers and micro technologists and used to develop customer-specific solutions. These manufacturing-oriented Microtechnologies provide the basis for the other areas of expertise at Fraunhofer EMFT.

2.3 Project Management Process

Given this broad portfolio with regards to the areas of expertise, Fraunhofer EMFT requires a stable Project Management process environment in order to successfully perform its research and development activities and meet the required standards for R&D at Fraunhofer-Gesellschaft.

As mentioned earlier, the Project Management process at Fraunhofer is based amongst others on the Project Management Body of Knowledge (PMBOK) issued by the Project Management Institute -see Figure 5 below (Fraunhofer-Gesellschaft e.V., 2017). In this *context, this subchapter intends to explain how the Project Management process at Fraunhofer EMFT is anchored into the institute's working environment*

Figure 5: PM Framework Fraunhofer-Gesellschaft e.V.



Source: *(Fraunhofer-Gesellschaft e.V., 2017, p. 8)*

At Fraunhofer EMFT, the Project Management system is subdivided into 7 phases as illustrated in table 3 below. These phases show the recurring activities that serve as a baseline for the stringent execution of Project Management at the institute. In addition, project managers are required to fill in checklists wherein, the respective phases are re-vised and cleared for release by the head of department, project acquirer, controlling, project manager and quality manager respectively.

Table 3: Description of Project Management process at Fraunhofer EMFT

Steps	Phases	Description

1	**Phase 1** -Initiation -Preparation of quotation -Planning of project draft	Clarification of the technical details and financial terms of contract (internal & external) of the project to be acquired
2	Creation of Quotation/Contract	Formal creation of -Proposal (for government & EU projects) -Quotation/draft contract (for industry & other clients)
3	**Phase 2** -Detailed planning of project	Detailed planning of project and update of schedules, final selection of project -team(s), -documents and -administrative rights
4	**Phase 3** -Execution of project incl. trials	Project execution and Monitoring & Control. If any changes necessary, review and documentation
5	Lessons learned	Securing of knowledge gained (also with unsuccessful projects) and stimulate change for future projects where necessary
6	**Phase 4** -Closure of project	Handing-over/presentation of agreed performances to client. Closing of project documents and administrative activities
7	End -Archiving of project documents	Final closure of all relevant aspects by project manager

Source: in accordance with the Project Management Best practice of Fraunhofer EMFT

Furthermore, a risk assessment is continuously conducted throughout the lifecycle of the projects in order to record and determine the level of risk that the institute is prepared to take as the project progresses. It is in this light, that I strongly recommend the application of Earned Value Management as an integral part of the Project Management process as a compensation for measuring the performance conducted throughout the lifecycle of projects and delivering reliable forecasts to assist project managers in the decision-making process. Also, being that Earned Value Management is already integrated into the PMBOK, speaks more for the easy access of its application into the Fraunhofer Project Management standard. As PMBOK is already in use as a reference standard within the Project Management environment at Fraunhofer.

2.3.1 Project Control and Monitoring

Project Control and monitoring is an integrated process in the Project Management system of Fraunhofer EMFT. It is also an integral part of the PMBOK guide to Project Management. It involves the process of collecting, measuring and distributing performance based information and assessing measurements and trends to affect process improvements. In order to effectively carry out the Monitoring and Controlling processes within projects, the following points are required (Project Management Institute, 2013, pp. 86–93):

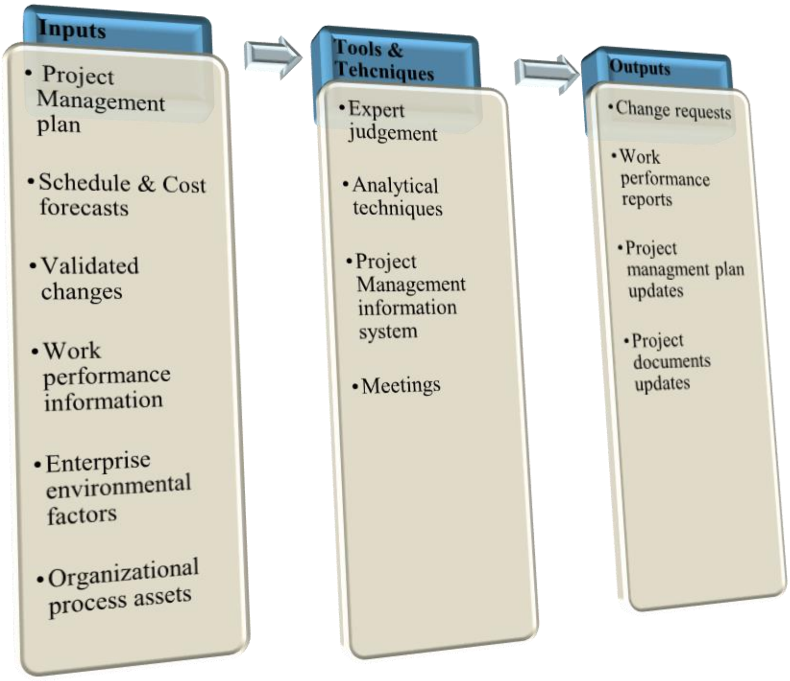
- Comparing actual project performance against the Project Management plan
- Assessing performance to determine whether any corrective or preventive actions are indicated and then recommending those actions as necessary
- Identifying new risks and analyzing, tracking and monitoring existing project risks to make sure the risks are identified, their status reported, and that appropriate risk response plans are being implemented
- Maintaining an accurate, timely information base concerning the project's products or services and their associated documentation through project completion
- Providing information to support status reporting, progress measurement, and forecasting
- Providing forecasts to update current cost and current schedule information
- Monitoring implementation of approved changes as they occur and

- Providing appropriate reporting on project progress and status to management (Project Management Institute, 2013, pp. 86–93)

As Murphey's eighth law rightly states: *"If everything seems to be going well, you have obviously overlooked something"*(Murphy, 2019). It is important that the performance in projects be regularly monitored in order to take corrective measures at an early stage. Once the progress in performance is accurately measured from the onset of the project, discrepancies from initial project plan can easily be identified and necessary measures taken to avoid further implications. On the other hand, if the performance is reported too optimistically, this could lead to the project manager not being able to maneuver the project as planned and add additional unforeseen costs in the form of resources burdened on the project without the certainty that the project would even achieve its desired goals (Burke, 2006, pp. 211–212).

To put formally, a Project Monitoring and Control system is implemented to identify and minimize the deviations from the initial project plan and consists of reviewing, analyzing and reporting the status of the project and implementing the corrective actions where necessary. Hence, it includes the set of policies, methods and tools that would ensure the achievement of the project targets (Hazir, 2014, p. 2). In this view, the policies and methods at disposal for the accomplishment of a Project Monitoring and Control system at Fraunhofer EMFT is the PMBOK guidelines which lays the fundamental processes upon which a system for monitoring and control is built. It covers three interconnected areas that form a process which is depicted in Figure 6 as follows:

Figure 6: Data flow diagram depicting Monitor & Control process



Source: (Project Management Institute, 2013, pp. 86–94)

Given the environment for Project Monitoring and Control as mentioned in Figure 6 above, a financial control tool is necessary for the execution of a monetary-based Analysis in order to measure and report deviations from initial project plans. Here is where the focus of this thesis is centered. For Monitoring and control related purposes at Fraunhofer EMFT, this thesis investigates the application of Earned Value Management as an analytical tool to measure the performance within projects in relation to the costs incurred in due process and using Monte Carlo simulations and Scenario & Sensitivity Analysis to depict and forecast the risks involved in the project lifecycle. It is important that a Project Management standard is used at the institute that is compatible with Earned Value Management. This requirement is duly fulfilled, as PMBOK is the standard used for Project Management at Fraunhofer EMFT.

3 Literature Review of Earned Value Management (EVM) and Project Control

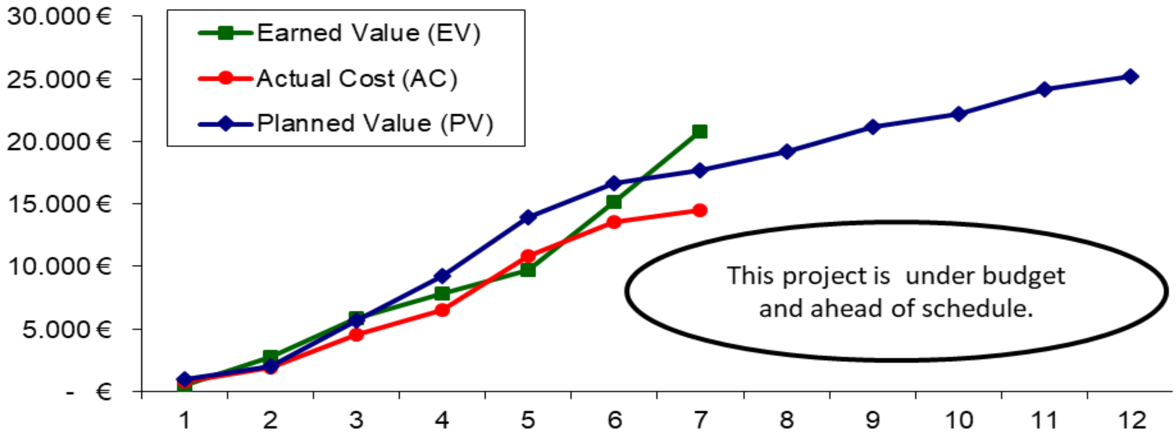
In this chapter, an in-depth literature is provided that serves as the base of this thesis. An extensive research has been conducted into the topic of Earned Value Management and its various functions in measuring and forecasting the performance of work within a defined Project lifecycle. Also, to facilitate the hypothesis of this thesis, in that, Earned Value Management is a suitable tool for measuring project performance at Fraunhofer EMFT, an empirical study was conducted on 150 projects spanning across five years of real-time projects acquired at Fraunhofer EMFT between 2014 and 2019. However, it is essential to note that most people consider EVM to be merely a measuring tool. This is not the whole story. Based on my literature research, EVM should be considered more like a management concept that combines the data needed in order to have a fully integrated performance management system within a Project Management environment. In the second subchapter, a comparison of EVM to alternate measuring tool such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) is provided, in order to assess the standing of EVM within the Project Management context. In subchapter 3.3, a look into the costing system at Fraunhofer EMFT is provided. Before finally, in the fourth subchapter, literature is provided towards project risk monitoring which entails the application of the Scenario-, Sensitivity- and Monte Carlo-Analysis.

3.1 Overview of Earned Value Management

According to the PMBOK guide, Earned Value Management is considered as a methodology that combines scope, schedule and resource measurements to assess project performance and progress. It is a commonly used method of performance measurements for projects. It integrates the scope baseline with the cost baseline, along with the schedule baseline, to form the performance baseline, which helps the Project Management team assess and measure project performance and progress. It is a Project Management technique that requires the formation of an integrated baseline against which performance can be measured for the duration of the project. The principles of Earned Value Management is applicable to all projects across all industries (Project Management Institute, 2013, p. 216).

In the Figure 7 below is a random demonstration depicting a graphical presentation of what an Earned Value report looks like. Across the vertical axis, the Planned Value, Actual Cost and Earned Value are depicted. Whereas, in the horizontal axis a timeline is depicted in weeks. This graph demonstrates that the random project is under budget and ahead of schedule.

Figure 7: An Earned Value Analysis performed on a random project



Source: (Vertex42.com, 2019)

In the graph depicted in Figure 7, the blue line represents the Budgeted Cost of Work Scheduled (BCWS) which is also referred to as the Planned Value (PV). It is used as the baseline against which the Actual Cost of Work Performed (ACWP) also referred to as Actual Cost (AC) and the percentage of the total budget actually completed at a given point in time (BCWP) also referred to as Earned Value (EV) are measured. As shown in the graph above, the Actual Cost lies below the baseline, in other words it is under the budgeted value at the defined time. Whereas, the Earned Value lies above the baseline which interprets that the work completed to that defined time is ahead of the scheduled plan. This graph depicts a typical report delivered to a project manager and stakeholders regarding the status of the project.

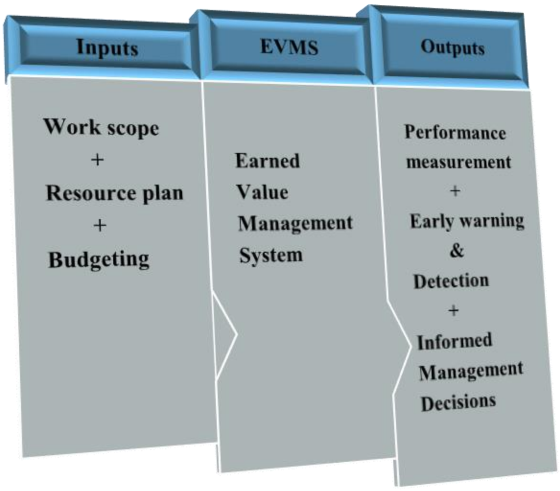
The Framework for the Earned Value Management System (EVMS) is further subdivided into 3 segments which are namely: (1) Inputs, (2) EVMS, (3) Output. These are depicted in Figure 8 below. These three segments are defined as follows (National Defense Industrial Association, 2014):

Inputs: In this segment, the requirements for the work scope are laid down for applying the Earned Value Analysis. These include a well-defined Work Breakdown Structure (WBS), an Organizational Breakdown Structure (OBS), an integrated process flow for determining the project baseline and assigning of cost resources expected to be spent for the duration of the project.

EVMS: In this segment, the Earned Value Management metrics are applied continuously during the lifecycle of the project. Such as regular Monitoring and Control of the Budgeted Cost of Work Scheduled, Actual Cost of Work Performed, and Budgeted Cost of Work Performed.

Output: In this segment, the results from the former segment are reported to all relevant stakeholders and in the case of deviations, corrective measures implemented in order to maneuver the project to the intended state in which it was predetermined to be or previously updated.

Figure 8: EVM Framework - EVMS Guidelines



Source: *(National Defense Industrial Association, 2014)*

3.1.1 Background of EVM

Earned Value Management finds its initiation when it became a fundamental approach to Project Management (EVM Project Management) in 1966. This took place when the United States Air Force mandated Earned Value (USAF EVMS) in conjunction with the other planning and controlling requirements on Air Force programs. The requirement was referred to as the Cost/Schedule Planning Control Specification (C/SPCS). Earned Value Management remained the same across the decades after its initiation. It has had periodic updates to its title: Cost/Schedule Control System Criteria (C/SCSC), Earned Value Management Systems Criteria (EVMSC), and the current 32 guidelines in the EIA-748 Standard for Earned Value Management Systems (EVMS). The EVM concept presented in these requirements is a sound management approach, that once incorporated on any type of project, whether research and development, construction, production, etc. provides all levels of management with early visibility into cost and schedule problems. Earned Value Management is now used on programs world-wide. Primary EVM users include the United States, Europe, England, Canada, Australia, China, and Japan. It is a requirement of many U.S. Government agencies, including the Department of Defense (DoD), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), the Intelligence Community, the Department of Homeland Security (DHS), the

Federal Aviation Administration (FAA) and Department of Transportation (DOT), Health and Human Services (HHS), amongst others (Humphreys & Associates Inc., 2012, p. 1).

3.1.2 EVM Metrics for Measuring the Project Baseline

In order to measure the baseline of any given project, three key determinants are required to monitor and control the performance of that project. These key determinants are as follows (Project Management Institute, 2013, p. 218):

- **Planned Value:** Planned Value (PV) also referred to as budgeted cost of work scheduled is the authorized budget assigned to scheduled work. It is the authorized budget planned for the work to be accomplished for an activity or Work Breakdown Structure component. This budget is allocated by phase over the lifecycle of the project, but at a given moment, Planned Value defines the physical work that should have been accomplished. The total of the PV is sometimes referred to as the Performance Measurement Baseline (PMB). The total Planned Value for the project is also known as budget at completion (BAC)
- **Earned Value:** Earned Value (EV) also referred to as budgeted cost of work performed is a measure of work performed expressed in terms of the budget authorized for that work. It is the budget associated with the authorized work that has been completed. The EV being measured needs to be related to the PMB, and the EV measured cannot be greater than the authorized PV budget for a component. The EV is often used to calculate the percent complete of a project. Progress measurement criteria should be established for each WBS component to measure work in progress. Project managers monitor EV, both incrementally to determine current status and cumulatively to determine the long-term performance trends.
- **Actual Cost:** Actual Cost (AC) also referred to as Actual Cost of work performed is the realized cost incurred for the work performed on an activity during a specific time period. It is the total cost incurred in accomplishing the work that the EV measured. The AC needs to correspond in definition to what was budgeted in the PV and measured in the EV (e.g., direct hours only, direct costs only, or all costs including indirect costs). The AC will have no upper limit; whatever is spent to achieve the EV will be measured (Project Management Institute, 2013, p. 218).

3.1.3 EVM Indices for Measuring the Variance in Project Performance

The Earned Value Management system also requires indices to measure the variances in performance against budgeted values that have been coined at the initiation of the project. The following indices are used in order to measure the variances (Project Management Institute, 2013, pp. 218–219):

- **Schedule Variance:** Schedule Variance (SV) is a measure of schedule performance expressed as the difference between the Earned Value and the Planned Value. It is the amount by which the project is ahead or behind the planned delivery date, at a given point in time. It is a measure of schedule performance on a project. It is equal to the Earned Value (EV) minus the Planned Value (PV). The EVM Schedule Variance is a useful metric in that it can indicate when a project is falling behind or is ahead of its baseline schedule. The EVM Schedule Variance will ultimately equal zero when the project is completed because all of the Planned Values will have been earned. Schedule Variance is best used in conjunction with critical path methodology (CPM) scheduling and risk management.
- **Cost Variance:** Cost Variance (CV) is the amount of budget deficit or surplus at a given point in time, expressed as the difference between Earned Value and the Actual Cost. It is a measure of cost performance on a project. It is equal to the Earned Value (EV) minus the Actual Cost (AC). The Cost Variance at the end of the project will be the difference between the Budget at Completion (BAC) and the actual amount spent. The CV is particularly critical because it indicates the relationship of physical performance to the costs spent. Negative CV is often difficult for the project to recover.

In addition, the schedule and Cost Variances can also be expressed in the form of efficiency indicators in order to create a measure of comparison for all types of projects without creating a bias in the values derived from the Earned Value Management system. These indices are as follows :

- **Schedule Performance Index:** The Schedule Performance Index (SPI) is a measure of schedule efficiency expressed as the ratio of Earned Value to Planned

Value. It measures how efficiently the project team is using its time. It is sometimes used in conjunction with the Cost Performance Index (CPI) to forecast the final project completion estimates. An SPI value less than 1.0 indicates less work was completed than was planned. An SPI greater than 1.0 indicates that more work was completed than was planned. Since the SPI measures all project work, the performance on the critical path also needs to be analyzed to determine whether the project will finish ahead of or behind its planned finish date. The SPI is equal to the ratio of the EV to the PV.

- **Cost Performance Index:** The Cost Performance Index (CPI) is a measure of the cost efficiency of budgeted resources, expressed as a ratio of Earned Value to Actual Cost. It is considered the most critical EVM metric and measures the cost efficiency for the work completed. A CPI value of less than 1.0 indicates a cost overrun for work completed. A CPI value greater than 1.0 indicates a cost underrun of performance to date. The CPI is equal to the ratio of the EV to the AC. The indices are useful for determining project status and providing a basis for estimating project cost and schedule outcome. (Project Management Institute, 2013, pp. 218–219)

3.1.4 EVM Indices for Forecasting Project Performance

For forecasting project performance, EVM offers a portfolio of indices which can be implemented at various timeframes (usually weekly or monthly) during the lifecycle of the project in order to be able to predict the final costs that can be expected based on the historic course of events that have occurred in the past. Also, it is important to note that each of these indices can be applied across all classes of projects, delivering “early warning signals” in case the project deviations exceed the tolerance limit. In other words, the expected costs that have been planned for at the start of the project. The following options explain how these indices can be implemented given the conditions warranted (Project Management Institute, 2013, pp. 220–221):

As the project proceeds in due progress, forecasts for the costs at the end of the project - commonly referred to as the Estimate at Completion (EAC)- might differ from the

Planned Value designated at completion. This is of course dependent on the rate of performance that has occurred prior to the date at which the forecast takes place. In order to forecast the EAC, project managers and their teams typically base the predictions on the Actual Costs incurred to that point in time in addition to the estimate to complete (ETC). This is commonly referred to as the bottom-up EAC method wherein, the Actual Costs and experience incurred for the work performed is used as a base in addition to the newly required estimate to complete for determining the estimate at completion.

This newly calculated EAC is compared to a range of simulated EACs depending on the risk Scenarios chosen for the estimated outcome. Also, one may find that the cumulated CPI and SPI values are typically implemented when calculating the EAC. At this point, it is important to note that within the Earned Value Management environment one may find various approaches to determining the statistical EAC. In this thesis only the three most common methods are explained as follows :

- **EAC forecast for ETC work performed at the budgeted rate:** This EAC method accepts the actual project performance to date (whether favorable or unfavorable) as represented by the Actual Costs and predicts that all future ETC work will be accomplished at the budgeted rate. When actual performance is unfavorable, the assumption that future performance will improve should be accepted only when supported by project risk Analysis.
- **EAC forecast for ETC work performed at the present CPI:** This method assumes what the project has experienced to date can be expected to continue in the future. The ETC work is assumed to be performed at the same cumulative Cost Performance Index (CPI) as that incurred by the project to date.
- **EAC forecast for ETC work considering both SPI and CPI factors:** In this forecast, the ETC work will be performed at an efficiency rate that considers both the cost and schedule performance indices. This method is most useful when the project schedule is a factor impacting the ETC effort. Variations of this method weight the CPI and SPI at different values (e.g., 80/20, 50/50, or some other ratio) according to the project manager’s judgment.

- **To-Complete Performance Index (TCPI):** The to-complete performance index (TCPI) is a measure of the cost performance that is required to be achieved with the remaining resources in order to meet a specified management goal, expressed as the ratio of the cost to finish the outstanding work to the remaining budget. TCPI is the calculated Cost Performance Index that is achieved on the remaining work to meet a specified management goal, such as the BAC or the EAC. If it becomes obvious that the BAC is no longer viable, the project manager should consider the forecasted EAC. Once approved, the EAC may replace the BAC in the TCPI calculation.
  In the case that the cumulative CPI falls below the baseline, all future work of the project will need to be performed immediately in the range of the TCPI (BAC) in order to stay within the authorized BAC. Whether this level of performance is achievable is a judgment call based on a number of considerations, including risk, schedule, and technical performance. This level of performance is displayed as the TCPI (EAC) line. (Project Management Institute, 2013, pp. 220–221)

The previous subchapters give an insight into the tools applied within the Earned Value Management environment in order to measure the performance of projects under the defined criteria. Actually, the concept of itself is a simple one, once one becomes accustomed to it. Simply put, Earned Value Management tools can be sub-divided into three segments:

In the first segment, we have the primary metrics such as the Planned Value, Earned Value, and the Actual Costs. These metrics form the fundament upon which all other measurable values are derived from. In their nature, there is no mind-boggling concept hidden behind them. They are simply values attained during the course of the project starting from initiation and followed through continued progress in work achieved.

The second segment, we observe the application of the schedule variance, Cost Variance and their respective indices, wherein, the variance in newly derived values differ from the initial Planned Values, these indices simply observe if the course of events during the lifecycle of the project occur as planned and eventually records deviations, allowing the stakeholders to have an early advantage to act accordingly in order to avoid unwanted circumstances during the continued lifecycle of the project.

The third segment, which involves the application of forecasting indices such as the EAC and TCPI provide an outlook into the future under the presumed circumstances that have been defined at the start of the project and furthermore, allows room for the project manager and stakeholders to either change the course of the project initially planned or implement measures that will force the project back on track.

In the table 4 below, is a summary of the calculations mentioned above.

Table 4: EVM Calculations Summary Table

Earned Value Analysis Table					
Abbr.	**Name**	**Lexicon Definition**	**How used**	**Equation**	**Interpretation of result**
PV	Planned Value	Authorized budget assigned to scheduled work	The value of the work planned to be completed to a point in time, usually the date time or project completion	-	-
EV	Earned Value	The measure of work performed expressed in terms of the budget authorized for that work	The value of all the work completed (earned) to a point in time, without reference to Actual Costs	**EV** = sum of the Planned Value of completed work	
AC	Actual Cost	The realized cost incurred for the work performed on an activity during a specific time period	The Actual Cost of all the work completed to a point in time	-	-
BAC	Budget at Completion	The sum of all budgets established for the work to be performed	The value of total planned work, the project cost baseline	-	-
		The amount of budget deficit or surplus at a	The difference between the work completed to		**Positive:** under planned cost

CV	Cost Variance	given point in time and the Actual Cost at the same point in time	a point in time and the Actual Cost to the same point in time	**CV** = EV – A C	**Neutral:** on planned cost **Negative:** over planned cost
SV	Schedule Variance	The amount by which the project is behind the planned delivery date at a given point in time, expressed as the difference between the Earned Value and the Planned Value	The difference between the work completed to a point in time, and the Actual Costs to the same point in time	**SV** = EV – PV	**Positive:** Ahead of schedule **Neutral:** On schedule **Negative:** Behind schedule
VAC	Variance at completion	A projection of the amount of budget deficit or surplus, expressed as the difference between the budget at completion and the estimate at completion	The estimated difference in cost at the completion of the project	**VAC** = BAC – EAC	**Positive:** under planned cost **Neutral:** on planned cost **Negative:** over planned cost
CPI	Cost Performance Index	A measure of the cost efficiency of budget resources expressed as the ratio of Earned Value to Actual Cost	A CPI of 1.0 means the project is exactly on budget, that the work actually done so far is exactly the same as the cost so far, other values show the percentage of how much costs are over or under the budgeted amount for work accomplished	**CPI** = EV/AC	**Greater than 1.0:** under planned cost **Exactly 1.0:** on planned cost **Less than 1.0:** over planned cost
			An SPI of 1.0 means the project is exactly on schedule, that the work actually done so		

SPI	Schedule Performance Index	A measure of schedule efficiency expressed as the ratio of Earned Value to Planned Value	far is exactly the same as the work planned to be done so far, other values show the percentage of how much costs are over or under the budgeted amount for work planned	**SPI** = EV/PV	-
EAC	Estimate at Completion	The expected total cost of completing all work expressed as the sum of the Actual Cost to date and the estimate to complete	If the CPI is expected to be the same for the remainder of the project, EAC is calculated using: If future work will be accomplished at the planned rate, use: If the initial plan is no longer valid, use: If both the CPI and SPI influence the remaining work, use:	**EAC** = BAC/CPI ---------------- **EAC =** AC + BAC-EV ---------------- **EAC** = AC + Bottom-up ETC ---------------- **EAC** = AC+ [(BAC-EV)/(CPI*SPI)]	-
ETC	Estimate to Complete	The expected cost to finish all the reaming project work	Assuming work is proceeding on plan, the cost on completing the remaining authorized work can be calculated using:	ETC = EAC-AC ---------------- ETC =	-

			Reestimate the remaining work from the bottom-up	Reestimate	
TCPI	To Complete Performance Index	A measure of the cost performance that must be achieved with the remaining resources in order to meet a specified management goal, expressed as the ratio of the cost to finish the outstanding work to the budget available	The efficiency must be maintained in order to complete the plan The efficiency that must be maintained in order to complete the current EAC	TCPI = [(BAC-EV)/(BAC-AC)] ---------------- TCPI = [(BAC-EV)/(BAC-AC)]	**Greater than 1.0:** Harder to complete **Exactly 1.0:** Same to complete **Less than 1.0:** Easier to complete --------------------- **Greater than 1.0:** Harder to complete **Exactly 1.0:** Same to complete **Less than 1.0:** Easier to complete

Source: *(Project Management Institute, 2013, p. 224)*

3.1.5 Requirements for EVM at Fraunhofer EMFT

As mentioned in the previous chapters, Earned Value Management is embedded in the PMBOK Guide which is in turn issued by the Project Management Institute (PMI) (Project Management Institute, 2013, pp. 217–224).

The PMBOK Guide lays the bedrock upon which Fraunhofer EMFT could integrate Earned Value Management into its Project Management environment. Before I proceed to elaborate on the requirements of Earned Value Management, let's look into the role it plays in the context of Project Control. For projects to be managed successfully, a communication channel for feedback is of utmost importance. This is also strongly emphasized in one of the three factors highlighted across the Project Management book of knowledge. Namely, time in conjunction with scope and cost. An integrated feedback process enables the project manager to identify deviations in the development of the project and provides sufficient time to apply corrective measures in order to either set the conditions as desired or maneuver the project back to where it was initially planned to be. With Earned Value Management, this task becomes easily implemented into the myriad of processes involved as the project proceeds once a stringent approach towards Earned Value Management is applied. Earned Value Management has been referred to as "management with the lights on" due to its capability to focus on the state of a project in a clear and objective manner. It provides organizations an approach required to integrate the management of Project time, Project scope, and Project cost (Project Management Institute, 2005, p. 1).

In addition, it helps answer regular questions that usually arise during the course of a project. Such as (Project Management Institute, 2005, p. 1):

- *Are we ahead of or behind schedule?*
- *How efficiently are we using our time?*
- *When is the project likely to be completed?*
- *Are we currently under or over our budget?*
- *How efficiently are we using our resources?*
- *What is the remaining work likely to cost?*
- *What is the entire project likely to cost?*
- *How much will we be under or over our budget at the end?* (Project Management Institute, 2005, p. 1)

For the Earned Value Management approach to work at Fraunhofer EMFT, there has to be a functioning Project Management system in place. This of course is already in use at the institute with the PMBOK guidelines. It serves as the standard to which all projects running at the institute will set their Framework towards. Earned Value Management starts off with a great proposal for an undertaking. Researchers require an understanding of the scope of the project, as this lays the foundation upon which a calculation of the estimated resources required for the work to be carried out is conducted. In so doing, the project size and impact becomes realistic. Once the scope of the project has been determined, the work involved to achieve the overall goal of the project becomes clear. Here is where Project Control is comes into play. The overall scope gets decomposed into smaller process groups, tasks or activities in order to optimally plan, execute and control the performance and accomplish the objectives of the given project this is also referred to as the Work Breakdown Structure (WBS) in Project Management terms. In the case of recurring projects, with similar characteristics, it might be useful to create project templates in order to populate project information such as the Work Breakdown Structure and determine the scope of the project at a manageable level. Next, the work packages are then assigned to key accounts to which an individual or a team is held responsible for (control accounts). Moving on, the scope is then allocated against a timeline for budgetary, scheduling and cost efficient purposes in order to facilitate an integrated performance measurement baseline. Once the execution of the project commences, Project Control plays a central role in measuring and analyzing the risks and performances against the baseline using the Earned Value Metrics and Indices in order to objectively measure the physical progress of work during the lifecycle of the project (Project Management Institute, 2005, pp. 23–28). On a final note, I believe that Earned Value Management can be integrated into the Project Management process of Fraunhofer EMFT, as all the above mentioned processes are already in place for Earned Value Management to be accomplished within the Project Management environment.

3.2 Comparison of EVM to alternative Performance Measurement Techniques

In order to justify the implementation of Earned Value Management in my literature review, I sort to find alternative performance measurement techniques out there that are available and in practice. Due to the limited capacity of this thesis, I chose two relevant performance measurement techniques, namely, the Critical Path Method (CPM) and the

Program Evaluation Review Technique (PERT). In the following two subchapters I present a comparison of the two techniques to EVM and deliver a justification for applying Earned Value Management.

3.2.1 A Comparison of EVM to CPM

The Critical Path Method (CPM) is a Project Management technique developed by Morgan R. Walker from DuPont and James E. Kelley from Remington Rand in the late 1950's. DuPont identified gaps in the traditional methodology of planning and scheduling, which eventually motivated them to develop an enhanced method that captures the planning and scheduling of projects better (Lenfle and Loch, 2010). According to an article by Kelley and Walker in 1959, they state that:

"*Among the major problems facing technical management today are those involving the coordination of many diverse activities toward a common goal."*(Lenfle and Loch, 2010)

In that, they elaborate on the fact that management plays a key role in coordinating the interrelated activities involved in achieving a common goal and proceeded to devise a tool now known as CPM that form a topological network of discrete activities representing the overall project scope (Koskela *et al.*, 2014, p. 28). In comparison to Earned Value Management, CPM focuses more on the scheduling part of the project. It is applied in projects to estimate the minimum project duration and determine the scheduling flexibility on the logical network paths within the scheduling Framework of a project (Project Management Institute, 2013, p. 176). Whereas, the Earned Value Management scope accompanies applicants throughout the lifecycle of the project encompassing scope, time and their variances and also providing KPIs that objectively report on the status of the project.

3.2.2 A Comparison of EVM to PERT

Program Evaluation Review Technique (PERT) similarly to CPM, finds its roots in the 1950s. Whereby the Navy's special project office of the United States were contracted with developing the Polaris submarine weapon system concerned about the growing nuclear arsenal of the Soviet Union. It is hereby, that the Navy's office of the United States developed a statistical technique for measuring and forecasting progress in research and development programs. PERT is a technique of Project Management used to plan, schedule, organize and coordinate all the activities in an appropriate manner within the project environment. PERT focuses on analyzing the tasks with their respective completion time in order to predict the overall completion of a project and most importantly determine the minimum time required to complete the project (Sharma *et al.*, 2015, pp. 2–3).Again, we see the focus laid on the scheduling of the project. Which resolves into the fact that Earned Value Management serves a broader scope within the Project Management environment. In the sense that, Earned Value Management grasps not only the scheduling aspect of projects but also takes into consideration that other factors play a role in the completion of the project.

3.2.3 Justification for applying EVM

Earned Value Management focuses on the performance of the work done in conjunction with the scheduling aspect amongst others within the project Framework (Project Management Institute, 2005, pp. 23–26). It is therefore, that I opt for Earned Value Management as the primary methodology in relation to the two above mentioned alternatives. In addition, for Earned Value Management to be employed at Fraunhofer EMFT, an all over approach will be needed to entertain the various aspects of a project undertaking. The Ease of use provided by Earned Value Management by means of the KPIs provided to inform the applicants about the current status of a project speaks for the efficiency in its application within the Project Management environment. Nonetheless, one should consider, using the CPM and PERT methodology in conjunction with Earned Value Management. The reasons therefore are that for one CPM provides a technique that is used in projects to predict activities and tasks in order to complete the project on time and secondly, PERT provides a probabilistic tool which is used in projects that have unpredictable tasks and activities such as research and development tasks. These options could serve the Earned Value methodology well in the decision-making process along the lifecycle of a project.

3.2.4 An integrative Project Control Procedure

Project Control lays its emphasis primarily on monitoring and reporting the execution of Project Management objectives within a given project in relation to scope schedule and cost along with quality and risk. In other words, it is a process involved in containing the performance and results within a tolerable range of the total work planned in a project within the Project Control process environment, Earned Value Management requires that the physical work progress be monitored and the planned budgetary Earned Value be credited along the progress line of the project (Project Management Institute, 2005, pp. 2–5).

Earned Value Management provides an all over integrated view of the project by means of its measuring metrics and indices which targets the planned effort that is represented in the cost values derived out of the metrics, actual progress depicted as the Earned Value, in other words a measurement of the actual performance that has taken place so far at any given time against the planned performance that should have been achieved and the Actual Cost representing the resources depleted in order to accomplish the results so far.

3.3 Fraunhofer EMFT Costing System

In accordance with the decision of the Federal Cabinet of 5.10.1973, the Fraunhofer-Gesellschaft is obligated to settle services on a cost basis at full costs. The content of the case was compared with that of the federal ministries BMF, BMVg, BMWi and BMBF. The Federal Audit Office was thereby integrated in due process. Since 1978, cost accounting has been used in all Fraunhofer Institutes and facilities and has since been further developed in accordance with the Framework conditions. The Cabinet resolution of the Federal Government was last passed and confirmed in the meeting of the Fraunhofer Committee on the 17.02.2009.

3.3.1 Overview of the Costing System

The cost accounting at Fraunhofer-Gesellschaft is used to allocate all expenses or costs incurred according to their origin. Expenses for the projects are hence, applied according to the following principles (Fraunhofer-Gesellschaft, 2010, p. 2):

- **Cost of Goods Sold**: this cost accounting only contains cost items for which expenses are equal to total expenditures in the same amount (cost of goods sold). Accordingly, this equates to no imputed costs (imputed interest, imputed profit, etc.)contained in the calculation. The annual post-calculation always ensures the complete conformity of the expenses and Expenditures in the business plan of the respective institute with the costs according to the cost accounting.
- **Full Costs**: All costs incurred at the institutes are allocated to the projects via the cost accounting system and assigned as cost units (full costs). Since the Fraunhofer Institutes only provide their services in the form of projects, cost units other than project sources of financing are not available.
- **Uniformity of Cost Accounting**: Cost accounting fulfills external requirements (calculation and accounting of projects in relation to grants and subsidies as well as their inspection by third parties) as well as internal functions (planning, and control of the institutes and their Projects). These functions can only be managed with the uniform application of cost accounting across all projects (Fraunhofer-Gesellschaft, 2010, p. 2).

3.3.2 Identification of Value Drivers

Within the conduction of the Analysis performed on 150 projects at Fraunhofer EMFT in the time range between 2014 and 2020 (see Scenario & Sensitivity Analysis in the workbook), the following value drivers were identified:

- **Man Hours:** Based on the Analysis performed, the planned man hours to any given project varies significantly to the manhours incurred across the 150 projects. This is also tied to an increase in unforeseen costs that eventually has an impact on the overall outcome of the respective project. It is therefore also applied in the Scenario & Sensitivity Analysis - with a Best, Most-likely and Worst Case Scenario, as well as in the Monte Carlo Analysis in order to generate data that can provide possible ranges of outcome (1,000 simulations)
- **Personnel Costs:** Based on the Analysis performed, the planned personnel costs calculated as part of the planned costs (cost baseline) also varies significantly across the 150 projects. Due to the impact it causes on the overall project outcome

it has been integrated into the Scenario & Sensitivity Analysis -with a Best-, Most-likely-, and Worst case Scenario Analysis, as well as in the Monte Carlo Analysis in order to generate data that can provide possible ranges of outcome (1,000 simulations)

- **Material Costs:** Based on the Analysis performed, the material costs calculated as part of the planned costs (cost baseline) also varies significantly across the 150 projects. Due to the impact it causes on the overall project outcome it has been integrated into the Scenario & Sensitivity Analysis -with a Best-, Most-likely-, and Worst case Scenario Analysis, as well as in the Monte Carlo Analysis in order to generate data that can provide possible ranges of outcome (1,000 simulations)
- **Other Costs:** Based on the Analysis performed, the other costs calculated as part of the planned costs (cost baseline) also varies significantly across the 150 projects. Due to the impact it causes on the overall project outcome it has been integrated into the Scenario & Sensitivity Analysis -with a Best-, Most-likely-, and Worst case Scenario Analysis, as well as in the Monte Carlo Analysis in order to generate data that can provide possible ranges of outcome (1,000 simulations)

The above mentioned value drivers show according to the Analysis performed that the Planned Values (cost baseline) and incurred values differ significantly across a large portion of the 150 projects selected. This of course demanded further investigation which took place by applying these cost drivers into the Earned Value Analysis and using the Earned Value Metrics and Indices to observe the overall outcome of the projects analyzed.

3.4 Project Risk Monitoring

According to a KPMG Project Advisory Leadership Series project risk management is defined as:

“a continuous process of identifying, analysing, prioritising and mitigating risks that threaten a projects likelihood of success in terms of cost, schedule, quality, safety and technical performance” (KPMG, 2014, p. 1).

This subchapter highlights the topic of risk monitoring in projects in order to identify deviations in work progress against the planned baseline and offer ways to mitigate those risks so that the likelihood of success in the project is not threatened. It is in this context, that the application of Earned Value Management as a tool for measuring the effective performance and delivering objective feedback comes in handy. With the utilization of its metrics and indices the applicant is in a position to provide a means to forecast future performance of the project based upon its past performance. Earned Value Management provides the calculation of cost and schedule variances and the forecast of a project's cost and schedule duration (Anbari, 2003).

Given that all project risks find their root in the uncertainty inherent in projects, due to their complex structures and technological connectivity, it would make sense to define project risk. According to the Project Management Book of Knowledge (PMBOK) project risk is defined as follows (Project Management Institute, 2013, p. 310):

"*Project risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives such as scope, schedule, cost, and quality. A risk may have one or more causes and, if it occurs, it may have one or more impacts*" (Project Management Institute, 2013, p. 310)

The set of risks in R&D projects is also to a certain extent dependent on the region in which the R&D activity is conducted. Yet still, through the interconnection of the global economy events in one region can offset consequences in across other regions. For instance, when we look at Europe, projected risk factors include (Aon Plc, 2019):

- Accelerated Rates of Change in Market Factors
- Economic Slowdown / Slow Recovery
- Commodity Price Risk
- Damage to Reputation / Brand
- Business Interruption
- Increasing Competition
- Cash Flow / Liquidity Risk
- Cyber Attacks / Data Breach
- Failure to Innovate / Meet Customer Needs
- Regulatory / Legislative Changes (Aon Plc, 2019)

Considering the impact of the highlighted bullet points one quickly grasps the intensity and consequence that the risk factors might have on the outcome of an R&D project. It is therefore a necessity that project risk monitoring be constantly reviewed with respect to the progress of any given project.

3.4.1 Scenario Analysis

As previously mentioned, uncertainty is an unanticipated factor inherent in projects. One can never exactly know when the impact might occur. It is in this context, that the Scenario Analysis plays a major role in proactively responding to certain criteria under the assumption that they might occur. The Scenario Analysis is also referred to as a deterministic simulation used frequently in project Analysis and schedule development (Shaikh, 2017). In this thesis, the Scenario Analysis conducted uses three given Scenarios. A Best-, Most-likely- and Worst case Scenario Analysis. Each bearing a different impact on the project outcome.

3.4.2 Sensitivity Analysis

Sensitivity Analysis is the quantitative risk assessment of how changes in a specific model variable impacts the output of the model. In projects, we are looking at how uncertainties and risks assigned to specific activities correlate with variance in the project. It is also a key result of Monte Carlo simulations of project schedules. Often referred to as a Tornado chart, Sensitivity Analysis shows which task variables (cost, start and finish times, duration, etc.) have the greatest impact on project parameters (Intaver Institute, 2019). In this thesis, a one and two variable what-if Sensitivity Analysis is performed using the weighting of man hours (in percent) across a range of percentages in relation to personnel, material and other costs for the one variable Sensitivity Analysis and secondly, man hours and overall project cost in a two variable what-if Sensitivity Analysis.

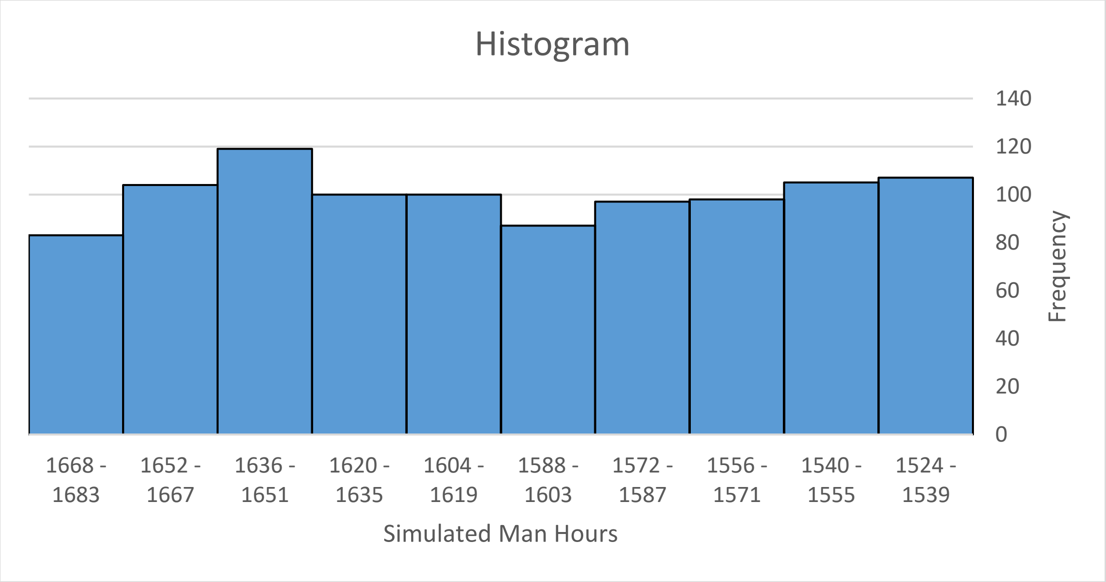
3.4.3 Monte Carlo Evaluation

Monte Carlo simulation is an Analysis tool used to analyze a given set of data for uncertainties. The history of Monte Carlo started when a mathematician by the name of Stanislaw (Stan) Ulam, presented a random number sampling idea to address a neutron diffusion problem to John Von Neumann who later presented the idea in a letter to Robert Richtmyer, in March of 1947 (Eckhardt, 1987, p. 132).

R&D projects such as those conducted at Fraunhofer EMFT, have the aim of producing results that are innovative and sustainable and by so doing generate revenue, retain customers and support existing infrastructures in compliance with federal rules and regulations. These undertakings are connected with costs that need to be accounted for. When the project is in its acquisition phase, the costs are usually estimated. Whereby, questions such as how was the amount calculated? or what is a given amount (calculated) based on ? The answers unfortunately do not always provide sufficient responses at the end of the day. Monte Carlo simulations, if run well, delivers answers to such questions and supports project managers in their decision-making process along the acquisitioning of projects.

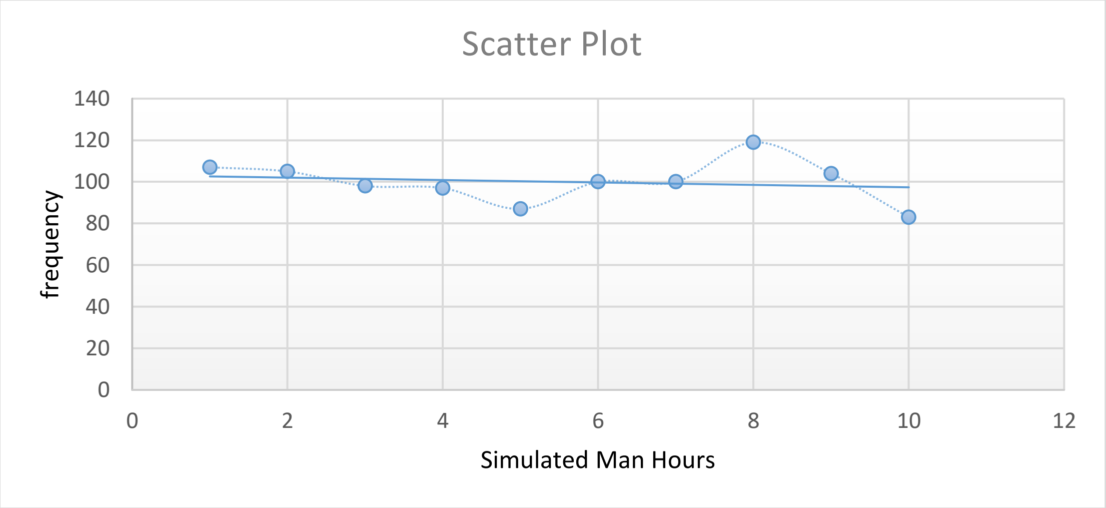
In this thesis, data was collected over a sample population of 150 projects spanning across 2014 to 2020. Thereby, comparing project planned budgets to Actual Costs that were incurred during the lifecycle of the projects and recording variances in the data collected with respect to time, cost and performance. The data is then used to perform an Earned Value Analysis before running a Scenario and Sensitivity Analysis. Finally, The Monte Carlo simulations bearing 1,000 iterations for each value driver are set to a specified probability distribution to generate costs that are eventually depicted via a histogram to show the frequency, mean, standard deviations and averages of the respective value drivers simulated. These depicted value drivers show the variances that exist between the Most-likely case Scenario and the simulated data depending on the randomly selected parameter in the probabilistic distribution course. For illustrative purposes the project with title 2018_20 has been selected to depict its simulated data for man hours, personnel costs, material costs and other costs respectively.

Figure 9: Histogram depicting simulated Man Hours for project 2018_20



Source: Self-Created

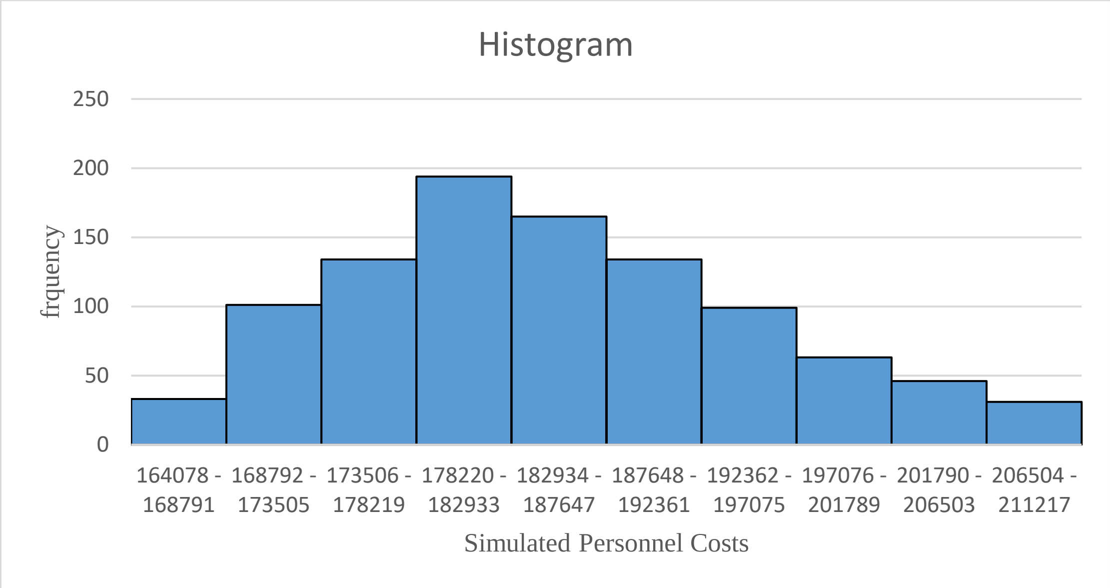
Figure 10: Scatter plot depicting simulated data Man Hours for project 2018_20



Source: Self-Created

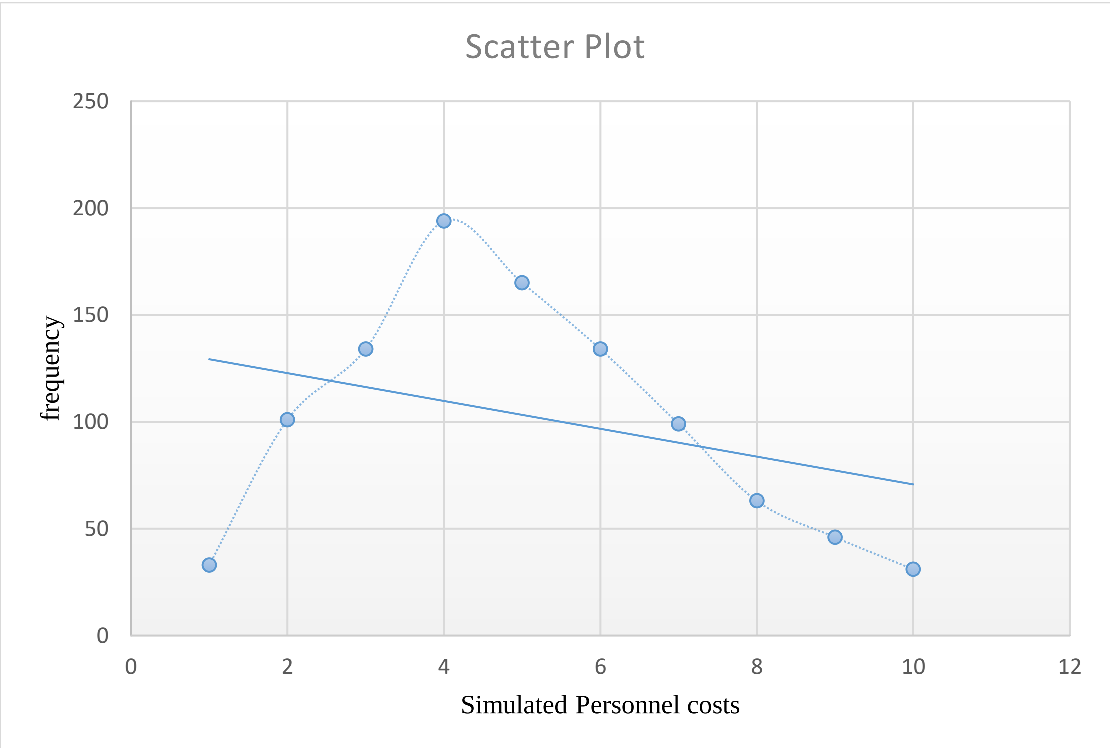
According to the graphs plotted in Figure 9 and 10, they depict 1,000 possible outcomes of simulated man hours under the given distribution parameter. It is showing very little variances in outcomes that will impact the total outcome of the project under the presumption that it is most likely for the man hours not to exceed 1,525 hours (see workbook for more information).

Figure 11: Histogram depicting simulated Personnel Costs for project 2018_20



Source: Self-Created

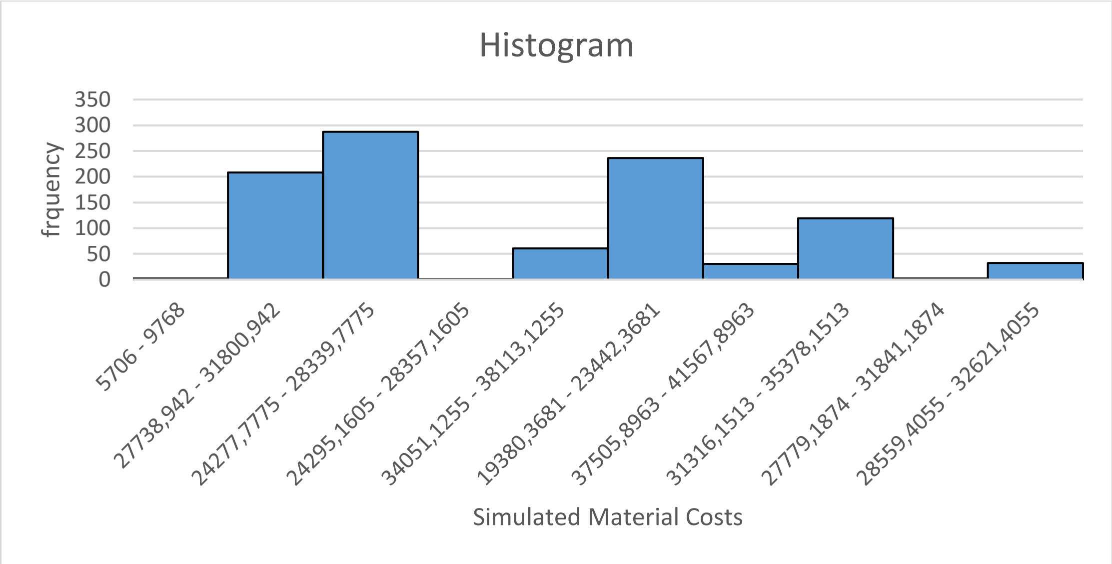
Figure 12: Scatter plot depicting simulated Personnel Costs for project 2018_20



Source: Self-Created

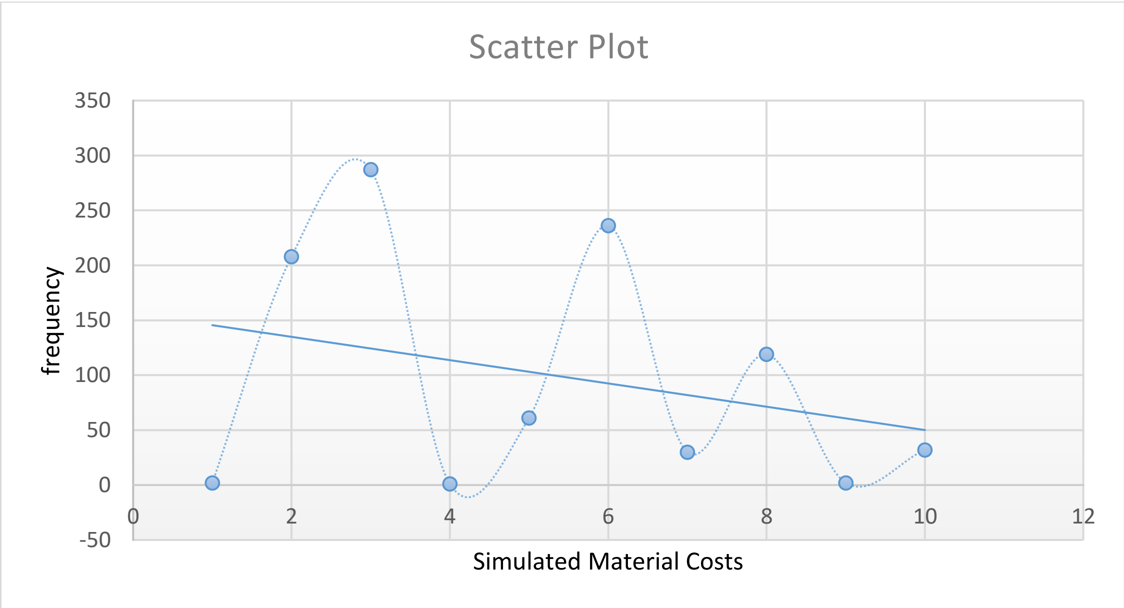
According to the graphs plotted in Figure 11 and 12, they depict 1,000 possible outcomes of simulated personnel costs under the given distribution parameter. It is showing a left skewed distribution parameter with significant fluctuations in outcomes that will impact the total outcome of the project under the presumption that it is most likely for the personnel costs to not to exceed 163,428.58 euros (see workbook for more information).

Figure 13: Histogram depicting simulated Material Costs for project 2018_20



Source: Self-Created

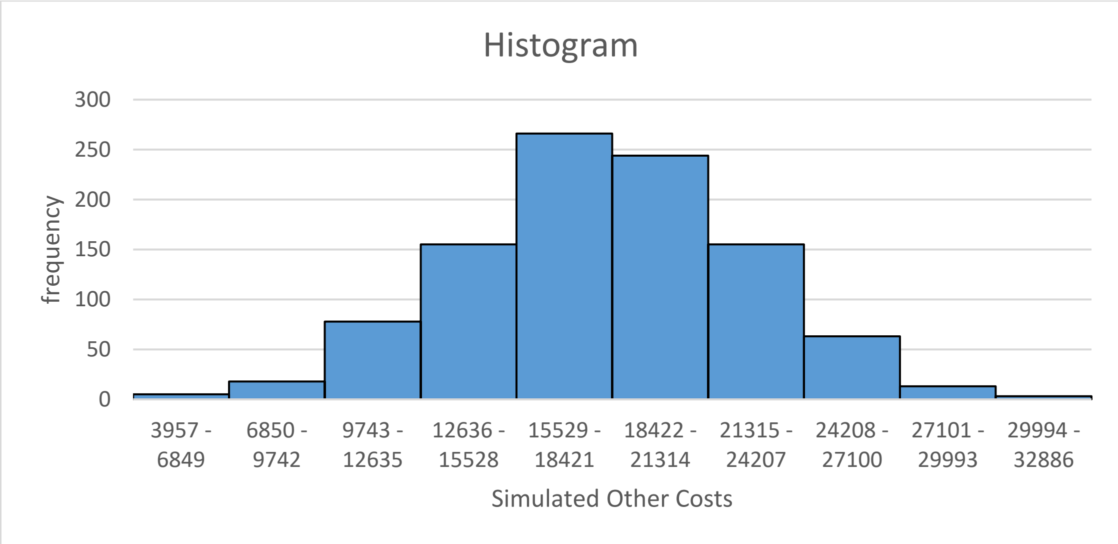
Figure 14: Scatter plot depicting simulated Material Costs for project 2018_20



Source: Self-Created

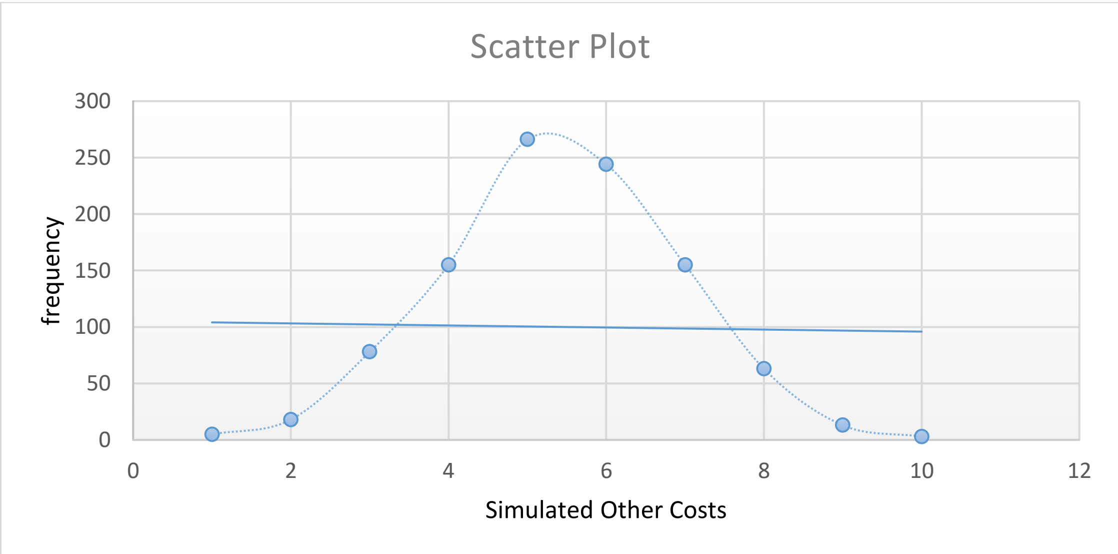
According to the graphs plotted in Figure 13 and 14, they depict 1,000 possible outcomes of simulated material costs under the given distribution parameter. They show a normal distribution parameter with significant fluctuations in outcomes that will impact the total outcome of the project under the presumption that it is most likely for the material costs not to exceed 24,761.90 euros (see workbook for more information).

Figure 15: Histogram depicting simulated Other Costs for project 2018_20



Source: Self-Created

Figure 16: Scatter plot depicting simulated Other Costs for project 2018_20



Source: Self-Created

According to the graphs plotted in Figure 15 and 16, they depict 1,000 possible outcomes of simulated other costs under the given distribution parameter. they show a normal distribution parameter with significant fluctuations in outcomes that will impact the total outcome of the project under the presumption that it is most likely for the other costs not to exceed 24,761.90 euros (see workbook for more information).

Given the above mentioned descriptions, a report to the project manager will contain information about the extremities derived from the simulations and compare these results to the initial plan which can be presented as follows:

Table 5: Comparison between Most-likely Scenario and Outcome on project 2018_20

Item	Most-likely Scenario	Maximum output simulated data
Man Hours	1,525	1,678
Personnel Costs	163,428.58 euros	211,217 euros
Material Costs	24,761.90 euros	46,332 euros
Other Costs	16,666.66 euros	32,883 euros
Total	**204,857.14 euros**	**290,432 euros**

Source: Self-Created

According to the comparison made in table 5 above, clearly, there is an urgent need for action. It does not necessarily have to be the case, nonetheless, according to the simulated data, there is a possibility that the approved budget in the amount of 190,000 euros is going to be exceeded by 100,000 euros. Of course, the frequency of the data was left out, which could eventually lower the exceeded amount down a budge. However, from a Project Controlling standpoint, it is absolutely necessary to communicate this information to the project manager and find solutions at an early stage to the problem at hand.

4 Application of Earned Value Management on Project Data

For the application of Earned Value Management on the project data, a Framework was conceptualized. Starting with the basic metrics such as the Planned Value, Actual Cost and Earned Value. The budget at completion is a given data from the project data worksheet, depicting the sum of all budgets established in order to perform the work. The Framework then proceeds to the variance Analysis. Whereby, the cost and schedule variances are recorded for every project. Ultimately, a variance at completion is calculated in order to show the budget surplus or deficit at the point at which the project was being analyzed. Furthermore, the cost and schedule performance indicators come into play. Here the efficiency of the planned resources are expressed as a ratio to the Actual Cost and Planned Value respectively. The Estimate at Completion is simply the total cost of all the work performed expressed as the sum of the Actual Costs to a given date plus the estimate to complete. The Estimate at Completion is calculated in four different ways depending on the criteria it falls under (see Excel workbook for EVM Metrics worksheet and the respective criteria of the estimate at completion). The estimate to completion depicts the cost expected to finish the remaining work of the project. This is also calculated in two different ways depending on the selected criteria (see Excel workbook for EVM Metrics worksheet and the respective criteria of the estimate to completion). The to-complete performance index shows the Cost Performance Index that must be achieved or maintained in order to meet the specific project goal. Which is simply a ratio the cost to finish the remaining work in relation to the budget available.

4.1 Overview of the Project Data

The Analysis of this thesis started off with the collection of 150 projects across a time range between 2014 and 2020. For the Analysis, a Framework was conceptualized in order to apply structure to the data. The frame starts with the project title. However, due to general data protection regulation the project titles were amended and given anonymous names. Next, the type of funding and approved budgets/revenues were collected. Moving on, the planned and real durations are compared to show if any variances in the scheduled work emerges. The Framework then proceeds to record all budgeted costs including man hours that were initially planned and compared to the Actual Costs incurred during the lifecycle of the respective project. Eventually, an Earned Value Management concept is integrated into the project data Framework to measure variances between the planned/budgeted and incurred/Actual Costs, showing the budget surplus or deficit implied at the given point in time which closes the project data Framework.

4.2 Application of EVM Metrics and Indices

As previously mentioned, the Earned Value metrics and indices are measuring techniques used to derive objective information about the current status of the project. During the analysis, a differentiation was applied to the Earned Value metrics in order to inform the reader about the current status of the projects. This was conducted using the if function in Excel. The function as applied states that if the end date in the project data worksheet is less than the selected date in cell "S1" (which is a dropdown list function) of the EVM Metrics worksheet then calculate 100% of the Planned Value as "Earned Value" otherwise, take the ratio of the actual to planned/budgeted man hours and multiply it with the Planned Value to derive a value depicting the value of work completed thus far. The variance metrics and performance indices are all derived within the EVM metrics worksheet of the Excel workbook.

4.3 Application of EVM Forecasting Indices

The forecasting metrics and indices are all applied within the EVM metrics of the Excel workbook in the format as provided in the formulas above the data. In order to avoid an error statement which occurred because either one of the denominators in the formula had a zero value hence, producing an error. This error value was simply replaced with a zero value using the if error function.

4.4 Implementation of the Scenario Analysis

For the Scenario Analysis, a Framework was conceptualized in the Excel workbook using the value drivers namely: project total costs, project duration, man hours, personnel-, material-, and other costs. These value drivers are then calculated under specific Scenarios namely the Best case, Most-likely case and the Worst case. Above the value drivers a dropdown list is provided wherein, the VLOOKUP Excel function was carried out dynamically connecting all relevant data related to the project selected to the value drivers under the best case Scenario. Also, the overhead costs are implemented to show their share in the total cost of the project.

4.5 Implementation of Sensitivity Analysis

For the Sensitivity Analysis, a one and two variable Sensitivity Analysis was conducted in order to depict the Sensitivity of the variables in conjunction to changes applied to the said value drivers. For the one variable Sensitivity Analysis, the man hours were given a range of changing values to show the impact the changes have on the personnel-, material-, and other costs. Also, a what-if function is used to conduct the Sensitivity Analysis. Finally, a graph is deployed to give a graphical interpretation of the values derived and their interrelation. For the two variable Sensitivity Analysis, the same procedure is employed except that this time the man hours and the total project costs are set as the variables to which corresponding and interrelated values are derived. This is also graphically demonstrated below the Analysis table in the Scenario and Sensitivity worksheet of the Excel workbook.

4.6 Implementation of Monte Carlo Analysis

For the Monte Carlo Analysis, a Framework was conceptualized in the Monte Carlo Analysis worksheet of the workbook using the value drivers as previously presented in the former subchapters. The Most-likely Scenario is used as a reference Scenario to which simulated values are distributed by means of Monte Carlo simulations. The simulated values are specified with distribution parameters which are assigned as follows: project duration and man hours are assigned uniform distribution parameters showing that they maintain a constant probabilistic distribution, meaning that the likelihood of deriving one value is the same as the next value. The personnel costs are assigned a triangular distribution parameter, showing that the frequency of the data simulated has a slight left skewed character according to the histogram and scatter plot. This indicates that the data carries a varied degree of variance with it. The material and other costs are assigned normal distributions show that even though there are extreme values at the tails the mass of simulated values are clustered around the mean value. One should also take into consideration that the material and other costs do not necessarily have to produce this form of distributions as project costs are best depicted using a three-parameter Frechet probability function (Love *et al.*, 2013, p. 329). This realization occurred during the latter phase of the Analysis of this thesis and will be taken into consideration, should the application of Earned Value Management be approved by the Fraunhofer EMFT Management.

5 Discussion of Results

In the following subchapters the results derived from the Analysis performed across the project sample population are discussed.

5.1 Evaluations and Implications

In order to present the results derived from the Analysis in a structured manner, I will proceed in presenting the results in the same structure as the Analysis was conducted. Bear in mind that the collection and organizing of the project data as described in chapter 4.1. serves as the fundament for the further application of the following subchapters.

5.1.1 Earned Value Management Findings

The Earned Value Management data starts by providing an insight into the general information of the respective project selected. It then proceeds into the application of the basic metrics such as the Planned Value, Actual Cost, Earned Value and Budget at Completion. These metrics capture the fundamental plan of the project and provide the necessary information that is required to further analyze the performance of the project. It is also therefore significantly important that these metrics depict the true nature of the status of the project. Otherwise, the other metrics and indices will misinterpret any objective report communicated to decision makers. The Framework then proceeds to apply the variance metric namely the cost, schedule and variance at completion metrics. Like I previously mentioned, it is absolutely necessary for the basic metrics to show the real status of the project in order to depict any deviations (variances in Project Management terms) from the planned or budgeted values assigned to the work to be done during the lifespan of the project. In addition, the Earned Value Management Framework provides performance indicators (cost performance and schedule performance indicators) that measure the attributes depicting the variances that have occurred. These indicators serve as signals to objectively inform the project manager about the performance and indicate whether further actions are required if necessary. The Estimate at Completion provides information about the cost situation in the project and what amount will be required to finish the work remaining. This metric gives the project manager a good insight into the financial status of the project and indicates whether the conditions are proceeding as planned or if further actions are required. The to-complete performance index sets conditions under which the selected project needs to perform in order to meet the overall project goal. On the overall, the Earned Value Management Framework, once applied properly, will contribute greatly towards delivering objective status reports to stakeholders. Nonetheless, its ability to predict future outcomes must be thoroughly investigated and if possible, used in conjunction with additive tools that can bolster the robustness of the information required.

5.1.2 Evaluation of the Scenario Analysis

The Scenario Analysis tool is an excellent tool for determining the conditions under which selected project attributes can be depicted in accordance with the pre-defined scope. It allows decision-makers to base the information required on justified reasons and delivers a flexible presentation of information for decision-making purposes. For this thesis, a Best-, Most-likely and Worst Case Scenario is implemented in order to give decision-makers a sense of orientation and awareness as to the impact of their decisions made thereof. The Scenario Analysis has contributed greatly in the Analysis of the project data and will hence serve significantly in future project acquisitions. As historical data will provide information on the do’s and don’ts for projects to achieve their respective goals.

5.1.3 Evaluation of the Sensitivity Analysis

The Sensitivity Analysis gives decision-makers the possibility to see how changes made in the input variables have an effect on the outcome of the project. For this thesis, the one and two variable Sensitivity Analysis helps bolster the robustness of the Scenario Analysis by providing justifiable evidence on the impact of changes made to project plans during the course of the project. It also gives insight into the predictive aspects connected to the project's performance.

5.1.4 Evaluation of the Monte Carlo Analysis

The Monte Carlo Analysis has contributed greatly towards the Analysis of the project sample population. With the help of the Monte Carlo Analysis, a Framework was constructed in accordance with the Most-likely Scenario supported by influential value drivers. The application of probabilistically generated simulations within a defined distribution, enables decision-makers to randomly create thousands of interdependent values that depict a broad array of results and confidently supports the decision-making process for successful project outcomes. In this thesis, 1,000 randomly simulated values have been generated using a VBA supported code in order to show the distributional pattern of the data generated and facilitate the criteria for the value drivers under investigation. The histograms and scatter plots give a visual intonation of how the distribution of the randomly determined value drivers behave. Like I previously mentioned, in order to present the respective project costs in an unbiased distribution, the application of a three-parameter Frechet probability function might serve better than a normal distribution parameter. The Monte Carlo Analysis would be a great tool to apply in conjunction to the Earned Value Management forecasting metrics and indices in order to present more confident data for decision-making purposes.

5.2 Critical Analysis of the Evaluations

During the collection and organization of data, for the performance of the Analysis, the project data had to be retrieved from the ERP system of Fraunhofer-Gesellschaft referred to as Sigma. The data had to be organized in a manner that provides sufficient information to the respective criteria chosen. For instance, the personnel costs for every project is the sum of all project participants with varying pay grades which is not depicted in the Framework. This is also true for the collection of the man hours which has an effect on the overall costs of the project. Also the planned and real duration of the projects do not include the planning and acquisition phases which play a significant role in the realization of the projects.

For Earned Value Management to be efficiently implemented it is necessary to record the events of progress in a timely fashion. For instance, weekly or monthly depending on the complexity of the project. In this thesis, firstly there was no possibility to record the progress of events on projects that have either closed or are near the closing phase of the projects. For me to be able to compare projects, a uniform approach had to be implemented. It therefore needs to be taken into consideration when evaluating the overall performance of the project population.

The Scenario and Sensitivity Analysis are based on random probabilities of my own choosing and therefore need to be mentioned as they form the base for the Monte Carlo simulations. Also the overhead costs should be seen as an integrated part of the respective value drivers (it is not to be seen as a separate cost item).

As previously discussed, the project costs in the Monte Carlo Analysis, would be better presented using the three-parameter Frechet probability in order to present an unbiased distribution of the simulated costs across the project sample population.

5.3 Implication of the Evaluations on Project Outcomes

The evaluations, which are based on the empirical study conducted imply that the application of Earned Value Management and risk monitoring tools such as the Scenario and Monte Carlo Analysis on projects at Fraunhofer EMFT will significantly bolster project managers to make robust decisions and in turn serve the institute well in identifying the proper allocation of resources for efficient and successful project outcomes in the future. It also shows that Project Management is an ongoing process that will need constant revision and updates in order to meet the desired set of criteria required at Fraunhofer EMFT.

6 Conclusion

On a final note, the empirical study conducted within the realm of this thesis, shows that the application of Earned Value Management enriches the Project Management environment by delivering objective information to stakeholders of projects in research and development organizations such as Fraunhofer EMFT. In fact, it is applicable across all types of projects using the Project Management Book of Knowledge as a guideline, giving that, the criteria for implementation is fulfilled. In addition, the implementation of the Scenario and Sensitivity Analysis backed by Monte Carlo simulations bolster the robustness of project monitoring during the lifecycle of the project.

Earned Value Management is considered to be one of the most effective performance measurement and feedback tools for managing projects. Allowing for possibilities to forecast future performance of projects by means of the past performance through the process of analyzing patterns and trends in the past for predicting future outcomes of projects. In order to fulfil the forecasting abilities of Earned Value Management, quantitative risk Analysis techniques such as the Monte Carlo Analysis provides useful measures in combination with Earned Value Management by specifying the likelihood of events and results in relation to the riskiness of project durations and costs (Bandeh Lou *et al.*, 2016, pp. 114–116).

Given the Earned Value Management Framework established for the empirical study, Earned Value Management Metrics and Indices are in the position to answer fundamental questions pertaining the management of projects which serves as a clear benefit for its implementation. Additional benefits include its ability to integrate other models such as the Scenario-, Sensitivity-, and what if Analysis models in order to target specific project environments. Also, it has the ability to force the proper implementation of project plans integrating scope, cost and time in its application. Finally, another major aspect of Earned Value Management is its potential use as an effective tool to communicate a clear, common picture of the project status to stakeholders. There is a clear trend of growing demand for the implementation of Earned Value Management as it gradually becomes the de facto standard and common language for controlling projects (Rodrigues, 2008, pp. 5–11).

6.1 Summary of Research

This research was conducted to provide an empirical study into the application of Earned Value Management and project monitoring on a project sample population of 150 projects spanning a time range between 2014 and 2020. The research also involves the application of risk measuring models such as the Scenario, Sensitivity and Monte Carlo Analysis in order to monitor the status of the projects and in due process delivering graphic presentations of the simulations conducted. Earned Value Management is an excellent tool for measuring and communicating project performance to its stakeholders in a clear and concise manner. In addition, it is easily integrated into the Project Management environment giving that it is part of the PMBOK guidelines recognized by the Fraunhofer-Gesellschaft. On a final note, Research and development organizations such as Fraunhofer EMFT, whose business strategy relies on the efficient and successful implementation of Project Management can increase its overall strategic value by implementing Earned Value Management into its Project Management platform.

6.2 Limitations of Research

The limitations present in this master thesis have already been emphasized during the course of the thesis. The empirical study was limited to 150 projects over a time span of six years in order to properly examine the data derived within selected timeframe of this thesis. The literature review covers 98 documents managed through the Mendeley reference management software spanning across conference papers, journal articles, reports, books, and webpages.

The Earned Value Management applications were mainly drawn from the Project Management guide (fifth edition) as it embodies the PMBOK Guide which is in turn implemented by Fraunhofer EMFT. Little attention was conducted to alternative Project Management establishments. Also, as previously mentioned, the Earned Value Analysis was not conducted on weekly or monthly basis due to the fact that a comparison between historic and ongoing project data needed to be created during the conduction of the empirical study.

The conditions set for the Scenario, Sensitivity and Monte Carlo Analysis such as the probabilities for the given Scenarios were randomly chosen and the Monte Carlo simulations were limited to 1,000 simulations due to the limited capacity of my end device to run the simulations.

6.3 Recommendations for Improvement

After a thorough research study across the project population, it is my finding that Earned Value Management can contribute greatly towards the management of projects at Fraunhofer EMFT. Fraunhofer EMFT can benefit from this empirical study by:

- Implementing the Earned Value Management metrics and indices across all projects at the institute in accordance with the PMBOK guidelines in order to create a consensus when comparing projects
- Implementing the Earned Value Management principles already in the acquisition phase of the projects
- Combining the quantitative aspects of Earned Value Management with the qualitative aspects of Quality Management within the Project Management environment
- Creating a reward system in order to encourage the facilitation of Earned Value Management
- Promoting an organizational culture of objective feedback processes pertaining project developments in order to act early enough on inherent or unexpected risks that occur during the lifespan of the projects
- Implementing risk monitoring tools such as the Scenario, Sensitivity and Monte Carlo Analysis to identify risks and apply appropriate measures if necessary
- Conducting status reports on a regular timeframe in order to measure the growth in performance within projects
- Creating an e-learning platform with regards to Earned Value Management, whereby news, updates and current issues can be discussed and analyzed

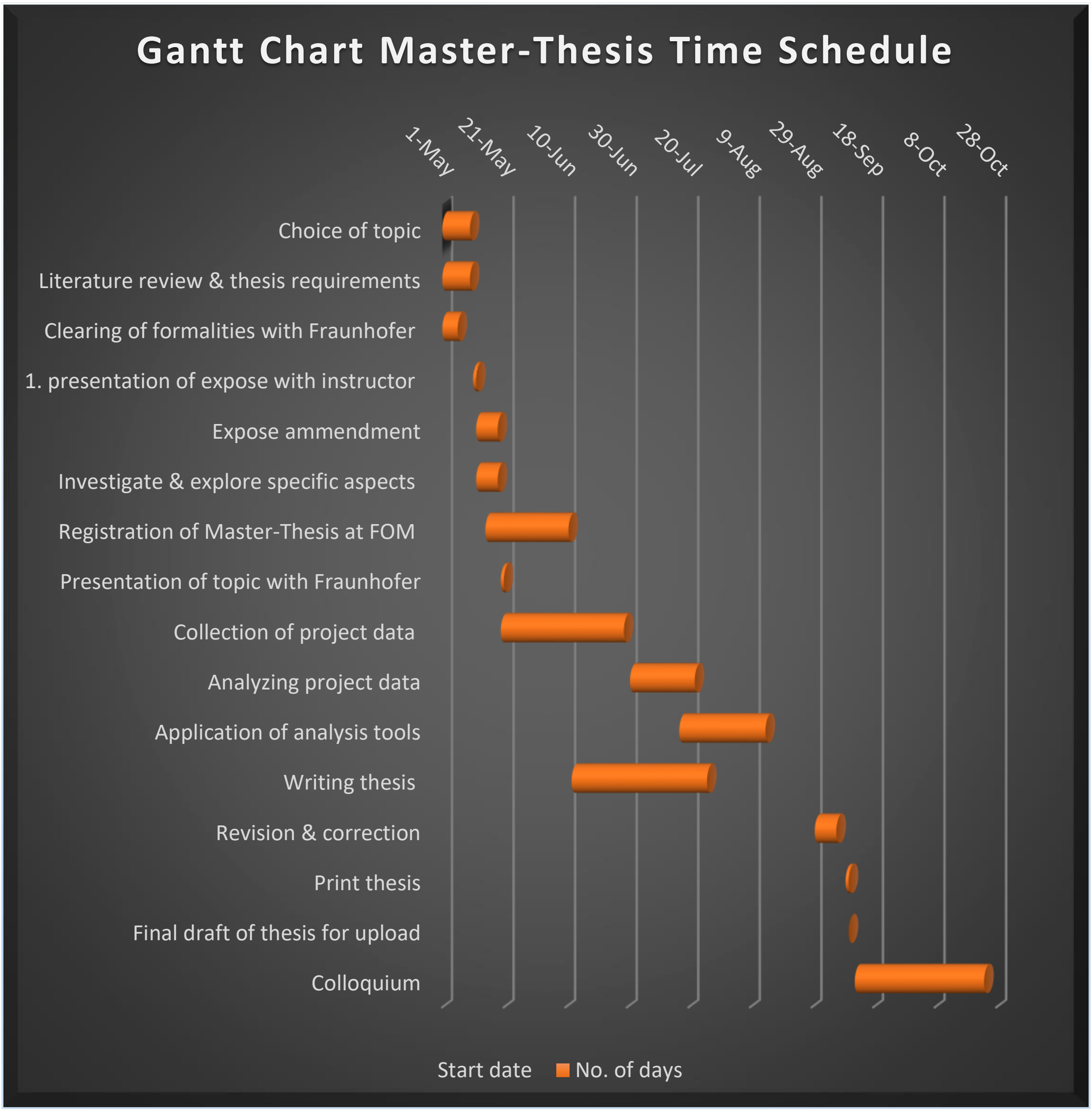
7 Thesis Time Schedule

Table 6: Master-Thesis Time Schedule

MASTER THESIS TIME SCHEDULE				
TASKS	**Start date**	**No. of days**	**End date**	**Phase**
Choice of topic	1-May	9	10-May	Prepara-tion
Literature review	1-May	9	10-May	
Clearing of formalities with Fraunhofer	1-May	5	6-May	
presentation of expose with instructor	11-May	1	12-May	
Expose amendment	12-May	7	19-May	
Investigate & explore specific aspects	12-May	7	19-May	
Registration of Master-Thesis at FOM	15-May	27	11-Jun	Applica-tion
Presentation of topic with Fraunhofer	20-May	1	21-May	
Collection of project data	20-May	40	29-Jun	
Analyzing project data	1-Jul	21	22-Jul	
Application of analysis tools	17-Jul	28	14-Aug	
Writing thesis	12-Jun	44	26-Jul	
Revision & correction	30-Aug	7	6-Sep	
Print thesis	9-Sep	1	10-Sep	
Final draft of thesis for upload	10-Sep	0	10-Sep	Final
Colloquium	**12-Sep**	**42**	24-Oct	
Total preparation days		10		
Total application days		79		
Total final days		**42**		
Total days to complete thesis		**131**		

Source: Self-Created

Figure 17: Gantt Chart Master-Thesis Schedule



Source: Self-Created

According to the time schedule depicted in both Table 6 and Figure 17, the total time forecasted for the thesis will take 132 days. This is broken down into a preparation phase, an application phase (maximal period after registration is 90 days) and eventually, the final phase which due to variances in the assigned date for colloquium has been scheduled till the 24th of October 2019 .This also implies an extension into winter semester 2019 in order to complete the MBA program as an enrolled student during the colloquium phase.

8 Appendix

8.1 List of Symbols & Formulae for Earned Value Metrics

List of Symbols

SV	Schedule Variance
CV	Cost Variance
VAC	Variance at Completion
SPI	Schedule Performance Index
CPI	Cost Performance Index
EAC	Estimate at Completion
BAC	Budget at Completion
AC	Actual Cost / also referred to as Actual Cost of Work Performed
EV	Earned Value / also referred to as Budgeted Cost of Work Performed
PV	Planned Value / also referred to as Budgeted Cost of Work Scheduled

A.0 Base Metrics:

The value of all the work completed (earned) to a point in time, without reference to Actual Costs.

EV = ∑ PV of work completed

Source: (Project Management Institute, 2013, p. 224)

8.2 Formulae for Earned Value Variance and Indices

A.1 Schedule Variance:

The cost comparison of what has been earned with what was budgeted.

SV = EV – PV

Source: (Project Management Institute, 2013, p. 224)

A.2 Cost Variance:

The cost comparison of what has been earned with what has been spent.

CV = EV – AC

Source: (Project Management Institute, 2013, p. 224)

A.3 Variance at Completion:

The cost comparison of the budget at completion with the current estimate at completion.
VAC = BAC – EAC

Source: (Project Management Institute, 2013, p. 224)

A.4 Schedule Performance Index:

An indication of how far behind or ahead of the planned work the project is (in terms of the value of the work accomplished); it tends towards 1.0 as the project progresses. It is of less value as the project nears completion.

SPI = EV / PV

Source: (Project Management Institute, 2013, p. 224)

A.5 Cost Performance Index:

The index of Earned Value to Actual Costs. Below 1.0 is unfavorable; above 1.0 is favorable.

CPI = EV / AC

Source: (Project Management Institute, 2013, p. 224)

8.3 Formulae for Earned Value Forecasting

A.6 Estimate at Completion:

The expected total cost of completing all work expressed as the sum of the Actual Cost to date and the estimate to complete (calculated in four ways):

EAC = BAC/CPI **(**if the CPI is expected to be the same for the remainder of the project)

EAC = AC + BAC – EV (if future work will be accomplished at the planned rate)

EAC = AC + Bottom-up ETC (if the initial plan is no longer valid)

EAC = AC + [(BAC-EV)/(CPI*SPI)] (if the CPI and SPI influence the remaining work)

Source: (Project Management Institute, 2013, p. 224)

A.7 Estimate to Completion:

The expected cost to finish all the remaining project work (calculated in two ways):

ETC = EAC – AC

(assuming work is proceeding on plan, the cost on completing the remaining work)

ETC = Reestimate (reestimate the remaining work from the bottom-up)

Source: (Project Management Institute, 2013, p. 224)

A.8 To-Complete Performance Index:

A measure of the cost performance that must be achieved with the remaining resources in order to meet a specified management goal, expressed as the ratio of the cost to finish the out-standing work to the budget available (calculated in two ways)

TCPI = [(BAC-EV)/ (BAC-AC)]

(the efficiency that must be maintained in order to complete the plan)

Greater than 1.0: Harder to complete

Exactly 1.0: Same to complete

Less than 1.0: Easier to complete

TCPI = [(BAC-EV)/ (EAC-AC)]

(the efficiency that must be maintained in order to complete the current EAC)

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10 ITM Checklist

Topics	**Comments/Suggestions**
Economics	In the economics area, projects are required to undergo critical scrutiny pertaining the applicability of the product or service in the industry sector and its market potential in the future. Herefore, the purchasing power of potential customers are measured against the investment portfolio
Marketing & Communication	In the area of marketing, the core areas of expertise of Fraunhofer EMFT need to be communicated to industrial organizations and governmental agencies in order to attract potential customers and optimize the product or service portfolio to meet those customer's needs
Human Resource & Leadership Competencies	Human resource & leadership competencies play a major role in the retainment of the institute's reputation to customers. Fraunhofer EMFT finds itself at the forefront of technological innovation and this is reflected in the intellectual capital that researchers, group leaders, project managers and head of departments possess in order to find new methods of approach and bring about innovation
Corporate Finance	In order to meet the demands for Research & Development at Fraunhofer EMFT, Projects need to be budgeted and financially analyzed to make sure that the work required is adequately financed
Strategic Corporate Management	Fraunhofer EMFT provides innovative solutions to organizations globally, for the institute to enter various international markets, the overall strategy needs to be tailored in order to develop diversified product and service portfolios and target the needs of those markets

International Business Law	Intellectual property is a major asset of projects at Fraunhofer EMFT. As researchers find new ways to create new products and services, patents are created in due process which serve as a reputational asset to the Fraunhofer-Gesellschaft as a whole
Value Based Controlling & International Accounting	Project Controlling plays a vital role in the achievement of project goals by continually assessing the performance incurred in the work packages and revising risk potentials as the projects develop towards their goal
Soft Skills & Leadership Qualities	Given the hierarchical nature at Fraunhofer EMFT, leadership qualities play a major role in achieving the institutes goals. Hereby factors such as decision quality and acceptance, satisfaction with decision processes and the integration of participant skills are central competencies that leaders need to exhibit
Management Decision Making	This thesis focuses on aiding the management decision making process by providing specific alternatives in consideration of meeting project goals
Digitalization	Especially in todays era of technology, digitalization plays a central role in projects. Projects acquired target specific topics such as safe and secure electronics , internet of things and autonomous processing in the industry, rendering solutions to problems the industry currently faces
Business Ethics and Sustainability	Fraunhofer EMFT has the following ethics integrated into its organizational policies: respect, excellence, responsibility and integrity. These values serve as the cornerstones for conducting business and maintaining relationships to the outside world

Declaration in Lieu of Oath

I hereby declare that I produced the submitted paper with no assistance from any other party and without the use of any unauthorized aids and, in particular, that I have marked as quotations all passages which are reproduced verbatim or near-verbatim from publications. Also, I declare that the submitted print version of this thesis is identical with its digital version. Further, I declare that this thesis has never been submitted before to any other examination board in either its present form or in any other similar version. I herewith disagree that this thesis may be published. I herewith consent that this thesis may be uploaded to the server of external contractors for the purpose of submitting it to the contractors' plagiarism detection systems. Uploading this thesis for the purpose of submitting it to plagiarism detection systems is not a form of publication.

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