CHALMERS
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Balancing Powertrain Attributes Using Object-Process Methodology

Master’s Thesis in the Master’s Programme International Project Management

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Department of Civil and Environmental Engineering
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Master’s Thesis BOMX02-17-89
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ABSTRACT

This researched studies a specific way of capturing, storing, sharing and accessing highly technical knowledge in a cross-functional context. The first objective of the study is to conclude on capturing highly technical knowledge in a system engineering architecture, the Object-Process Methodology. The second objective is to evaluate accessing and managing the highly technical knowledge with Object-Process Methodology in a cross-functional context.

The theory review consists three related works, 3-T framework, Knowledge Query and Request framework, and Knowledge Recommendation framework. The theory serves as base for evaluating representing and sharing the highly technical knowledge with the simplified modeling architecture. The research uses inductive approach. The data collection process involved unstructured interviewing of 15 participants, more than 3 months of observation method within the Volvo Car Corporation social setting, literature review and documents examination.

Highly technical knowledge can be represented using Object-Process Methodology. Constructing physical system diagrams allows transformation of real vehicle system into the modeling environment in form of objects, processes and relationships between them. Processes representing systems functions (such as noise or vibration), are connected with relationships to objects' states, and explaining their behaviour in the system. Application of Object-Process Methodology for accessing the knowledge eliminates multiple processes of knowledge management frameworks review in the theory section. Powertrain attributes can be balanced more efficiently using Object-Process Methodology. Due to the system agility, the project management practice process in the vehicle development process will be empowered.

Key words: Knowledge Management, Knowledge Recommendation, Knowledge Query, Object-Process Methodology, Powertrain Attributes, System Engineering.

Contents

Preface

The research project is a master thesis work representing a final dissertation for Dual Award of two postgraduate programmes, M.Sc. in International Project Management at Chalmers University of Technology in Sweden and M.Sc. in Project Management at Northumbria University in the United Kingdom. The study was contacted in close collaboration with Volvo Car Corporation in Gothenburg, Sweden.

The researched project was initiated by a Senior Technical Expert from Volvo Car Corporation, who has together with his colleagues identifies knowledge gaps in capturing, storing and sharing knowledge in vehicle development process. Therefore, the aim of the study is to come up with a solution that allows highly technical knowledge being represented in a system engineering architecture and shared across cross-functional business units. The investigation focuses on two domains. First, a specific way of storing knowledge. Second, accessing knowledge and its distribution to other individuals across an organisation. In order to conclude on knowledge managing and distribution in the cross-functional context, number of related works has been reviewed.

The research project encloses inductive approach as the theory is generated from data collection and analysis, with an epistemological orientation being interpretivism. The case study research design had been conducted using various research methods such as observation, unstructured interviews, literature review and documents examination. The participants in the study are employees of Volvo Car Corporation in Sweden and fully anonymous.

The study brought up a proof of a possibility to store knowledge in a system engineering architecture and evaluated the practice against three academic works. As a result of that, the study brings a new approach to balance powertrain attributes and increasing efficiency of project management practice.

Gothenburg, August 2017.

Martin Simak

Acknowledgements

I would like to thank my supervisor Martine Buser who has been guiding and supporting me through the research project. At the same time, I would like to thank to Allan Osborne who has enabled me to understand research methods, which I have used to perform the research.

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My gratitude to all research participants, whose support and contribution were significate success factor for this project.

To all of you,
Thank you.

Martin Simak.
Gothenburg – Sweden, September 2017.

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1 Introduction

1.1 Problem identification

In last few years, a formal unit to handle balancing powertrain attributes has been established in Volvo Car Corporation, being a part research and development organisation. The unit consists of attributes leaders managing balancing process of various attributes in car projects such as noise, vibrations, emissions, etc. Soon after establishing formal roles in the new unit, a group of senior experts have identified shortcomings in the attributes balancing process. The shortcomings have been identified by running the attributes balancing operations on a daily basis, therefore, disclosed many pain points in the process that have been results of the intense cross-functional interaction. As a result of that, a challenge has emerged. A challenge, which asks for an innovative solution that will drive a change in the attributes balancing process by increasing digital maturity of the project management practice.

1.2 Problem description

The operations in a vehicle development process (VDP) is service oriented based on deep functional knowledge and accumulated experience. The expertise owned by expert workforce is not available for other people in the organisation and it generates a continual need for intense interaction between functional departments. Such interactions are time-consuming and therefore very expensive. Moreover, a certain level of misunderstanding between organisational members is unavoidable. One of the common reasons is the represented by the difference between “languages” that two or more individuals use to express themselves. Business units approach problems from different perspectives, i.e. some rely on knowledge stored in documents, others try to track knowledge amongst organisational members. Such deviations create a significant level of misinterpretation. Based on that, a reliable model for capturing, storing and communicating highly technical knowledge is desired. The ideal solution will allow traditional knowledge queries to be addressed in a short time of period and on the higher level change the knowledge management (KM) transactions from pull to push. In that case, knowledge transactions are not requested by individuals but offered to them as a mean of assistance managed by fully operating digital solution. Furthermore, such solution will help to post-process the knowledge of various systems and show the interaction between them. That will not just help to track the organisational knowledge and avoid losing it, but also show the interdependencies between the system functions and attributes in real-time for purpose of tracking the organisational knowledge. Therefore, increase the efficiency of managing projects mainly in the first three project management process groups of initiating, planning and executing (Project Management Institute, 2013).

1.3 Purpose

The master thesis project was initiated to execute a feasibility study for implementing of Object-Process Methodology (OPM) modelling language as the main tool used in the KM. Secondly, to develop a top level model which will show progressive approach in the handling the KM process within the VDP including secondary application in showing interdependencies. The methodology was chosen by organisational experts, thus the investigation focuses on the implementation of the OPM approach within a small cross-functional unit, Powertrain Attributes balancing team. Implementation of OPM should significantly reduce cross-functional misinterpretation and allow re-using accumulated knowledge in a best possible way. The top level model should describe a progressive approach for KM and use OPM as a base system to avoid common redundancy with other methodologies.

1.4 Research questions

In order to deliver the desired project outcome and reach scientific contribution of the thesis project, the research questions (RQ) have been formulated as follow:

RQ1: *How can highly technical knowledge be represented in system engineering architecture?*

RQ2: *How can the knowledge be accessed in a cross-functional project environment?*

1.5 Research goal

The overall goal is to come up with a conclusion that is going to reflect on the application of the OPM within a strategic model that will increase the efficiency of the project management practice in the VDP.

1.6 Research objectives

To meet the goals of the research project the deliverables are necessary to be set. The output of the project is required to deliver (1) academic review of relevant theory, (2) description of methods used for the research, (3) presentation of Object-Process Methodology, (4) presentation of a case study, (5) analysis of interaction between theory and case study using a strategic model, (6) conclusion on the research question, (7) recommendations and limitations for implementing the strategic model and using OPM for its baseline.

1.7 Thesis outline

Chapter 1 - Introduction

Based on detail expertise of ongoing processes, the objectives, and goals of the research work are set.

Chapter 2 - Method
The chapter provides a description of the research strategy, design, and methods used in the processes of data gathering. Research quality and ethical considerations are discussed at the end of the chapter.

Chapter 3 – Related Works
The chapter provides a presentation of related academic works in the research of knowledge management. Three frameworks are discussed.

Chapter 4 – Organisational Challenge
The first part of the chapter briefly summarizes the dynamics of the automotive industry and a general need for digital changes. Consequently, the introduction of Volvo Car Group (VCG) and the background behind its global transformation is provided. The transformation that is not finished yet, however, aiming to rapidly increase sales at international markets and build customer's loyalty for Swedish car manufacturer. In the next part of the chapter, the call for digital solutions among functional units in R&D Powertrain department is presented. The call that is rooted in the desire to digitalize parts of the vehicle development process.

Chapter 5 – Object-Process Methodology
The chapter introduces Object-Process Methodology (OPM), a holistic system engineering modelling approach that consists of 20 symbols (Dori, 2016). Fundamental entities and relations between them are presented, as well as natural language that accompanies system diagrams.

Chapter 6 – Powertrain Attributes Mapping
The chapter presents powertrain attributes balancing case. The case is represented by Object-Process Methodology diagrams created in OPCAT software. The diagrams are accompanied by description explaining the relationship between attributes and systems as well as the general idea behind modelling the behavioural structure.

Chapter 7 - Analysis
The chapter provides readers with a discussion about OPM implementation within the three frameworks presented in chapter 3. Moreover, an explanation of balancing powertrain attributes with knowledge management approach using OPM is provided.

Chapter 8 - Conclusion
The chapter summarises the research projects, offers answers to the research questions and recommends areas for future research.

2 METHOD

This chapter provides detail explanation of the research strategy, research design and research methods applied in the research project. The research has started by having an informal discussion, so-called "grapevine" (Boddy, 2002, p. 76), with individuals at the functional and managerial level in Powertrain R&D department. The early stage of the research took the advantage of the incredible fast way of passing information with face-to-face communication. The intense interaction with organisational experts has discovered existing shortcomings in KM processes leading to information sharing and communication between various teams. After the broad understanding of the context and purpose of the study, a formal strategy for data collection was formed. Subsequently, the input for the case study has been divided into to two types of data, primary and secondary data. The primary data, defined as "original data collected for a specific research goal" (Hox and Boeije, 2005, p. 593), are the main source of information for the research goal. On the contrary, the secondary data are "originally collected for a different purpose and reused for another research question" (Hox and Boeije, 2005, p. 593). The secondary data form a base pillar for the system diagrams and observing limitations in the process. In the case of this research method, the secondary data are presented in the first place, because the research started by collecting information about already existing systems in the organisational database.

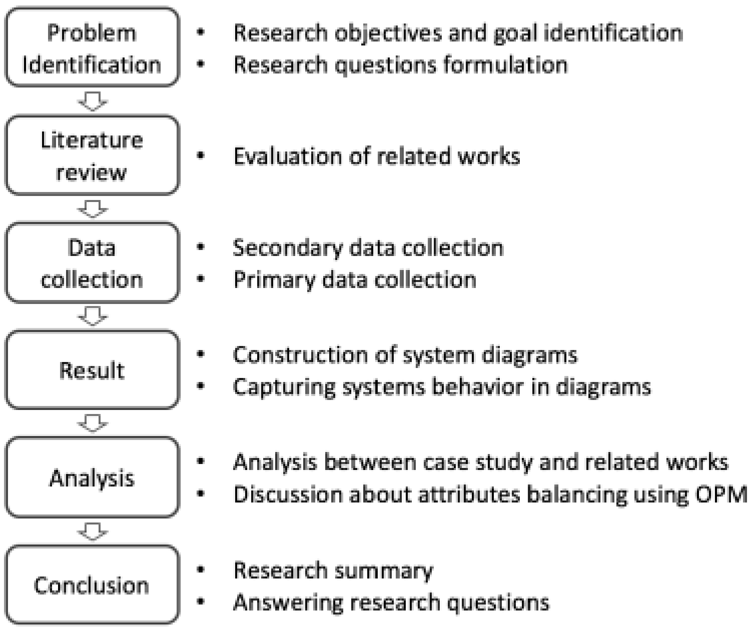


Figure 2.1 Research process

2.1 Research strategy

The research strategy chosen for the dissertation project is qualitative, as the data collection process uses words instead of quantification. As the research is based on individual's viewpoint on the organisational processes, application of quantitative research methods is not applicable. The deployment of the qualitative research strategy takes advantage of its flexibility and possibility of less structuralised process of data collection and analysis, as well its epistemological and ontological positions. The emphasis is on viewing the world through the eyes of participants being studied. The primary relationship between theory and research is defined as inductive, whereby the theory is generated from the collection and analysis of data, also known as grounded theory approach (Bryman, 2012). However, some elements of deduction are applied as a collection of further theoretical data has been required to establish conditions in which the theory holds.

The epistemological orientation of the research is interpretivism, underpinned by the main idea that humans cannot be considered as natural objects (Bryman, 2012). In other words, the investigation of the social actors who create an organisation cannon be conducted by using the same methods and procedures as an investigation in natural sciences. The understanding of the social system is generated by individual's point of view on reality in which they live rather than observing their behaviour within the whole. In that sense, the data collection process in a cross-functional environment has to consider certain deviations created by individual's opinions, which are often connected to an individual's profession. A certain level of interpretation is created across a wide range of engineers being involved in the product development process, therefore, an investigation of same systems within the process may lead to different results.

The ontological position of the research is constructionism, based on the idea that social phenomena are not independent on social actors (Bryman, 2012). The social world, in the case of this research the organisation, is strongly influenced by its individuals as a part of an ongoing and dynamic transformation. The behaviour of the individuals influences the social reality within the organisation continuously through the process of construction and reconstruction. As a project in product development involves many organisational members with distinct professions, their everyday interaction changes the organisation itself in a dynamic way. And what is regarded as a status quo today, often differs from the state of the organisation and its social groups in the future.

2.2 Research design

To provide a conceptual framework for the data collection and analysis, a case study has been chosen as the research design. In this research, a part of Volvo Car Corporation is studied within the case study. In particular, processes in few business units within the research and development organisation, which are listed in chapter 4, have been studied. For further distinction, the exemplifying case (Bryman, 2012) represents the case study in this research, with the objective capture the circumstances and conditions in the everyday environment to provide a context for the research questions to be answered. An access to the organisational context is crucial for understanding the social setting in the workplace and making up a conclusion. However, elements of other types of cases are also implemented.

2.3 Research methods

Selection of proper techniques for data collection is a crucial activity in the early stage of the research project. Using the flexibility of the qualitative research strategy, some methods have been applied since the beginning of the data collection process, and others have been added throughout the process. As Bryman points out, the qualitative research incorporates several diverse research methods that differ from each other considerably (Bryman, 2016, p. 377). Also in this research project, diverse research methods have been employed in the process of data collection.

2.3.1 Literature review

The main purpose of the literature review is to develop an understanding to already known research and knowledge in the area of interest (Bryman, 2012). Therefore, an analysis of the work of others has been conducted and reviewed in the literature section. Such review does not just help to understand already conducted research and avoid a certain level of double work, but it also helps to position the research towards the desired achievement. Such position is strengthened by extending the knowledge base within the particular area of interest and understanding the academic discussion between scholars. Furthermore, ideas and arguments of other researchers are used to support data analysis and answering the research questions. In this research project, the scholarly review has been conducted, using as a primary source the electronic library at the Chalmers University of Technology. A number of international journals have been accessed (i.e. Organization Science, Information Processing and Management, Techinnovation), relevant articles as well as handbooks, examined. Eventually, the literature with a direct connection to the area of this research has been carefully reviewed. An interactive software, NVivo, has been used for clustering relevant information under a time limited trial license.

2.3.2 Observation

Observation, also widely referred as ethnography (Bryman, 2012) is one of the main research methods employed in the project. Participants within a cross-functional environment in the office at Volvo Car Corporation's headquarters were observed for the time period of 4 months as a part of student dissertation programme offered by the organisation. Such programme allows the researcher to access highly confidential and closed social setting. The observation was done by daily working interaction as attending meetings, collaborating on projects and being part of informal discussions around in the office. All the participants involved have been aware of the research project and the role of the researcher in their social setting. Daily interaction in the workplace helped to engage participants, as they tend to be more engaged than if they are just randomly interviewed (Bryman, 2012). The findings from the observation process were captured and stored with fields notes and further post-processed by the researcher. The output from the observation served as the input for further data collection with other methods such as document examination and interviews.

Individuals observed allowed the researcher to access and identify relevant documents to be examined, and also to initiate the process of participants sampling for interviewing.

2.3.3 Documents examination

Another method employed in the process of the data collection was documents examination. The documents examined for the purpose of the research has not been created with the intention to support the research, rather for regular business operations across different teams within Volvo Car Corporation's research and development business unit. Such documents are mostly stored in the organisational cloud storage and in individual's computers. The access to highly confidential documents was given by senior engineers and managers. The selection of the documents to be examined was done by informal discussions with participants during the observation period. Furthermore, some documents allowed to forward the researcher to other documents via hyperlinks. The documents examined were mostly Word documents, Excel sheets, and PowerPoint presentations containing various diagrams and pictures. The data gathered in the process of the documents examination were used for general understanding to systems and processes managed by the social actors, and as an input for diagrams creating. The base for the behavioural diagrams is formed by physical car components, which design and functions were derived from the documents that are part of the organisational intellectual property. Furthermore, the behaviour of attributes in the physical systems was captured by conducting interviews.

2.3.4 Unstructured interviewing

As interviewing remains the most employed role in the qualitative research (Bryman, 2012), however, has a minor role in the scope of the data collection process within this research project. At the same time, the method has played very important role as it provides very sensitive information about the behaviour of the systems that allows mapping powertrain attributes within the physical systems. In the same manner, the input from participants was used in the general understanding of organisational processes, limitations and possibilities within the social setting. The interviews conducted for the secondary data gathering had unstructured character, without any prepared questions. Instead, interviewees were presented with the problem during interactive sessions lasting less than one hour, which has been recorded on an offline recording device. Then, their point of view on the problem has been processed by the interviewer while listening to the records again and captured in the systems diagrams. A typical output of an interview was finding of how an attribute state changes with systems functions, which may be for instance increasing or decreasing engine revolutions. Such output seems to be easy to gain, however, the presentation of a system to the interviewee and an open discussion that leads to clear understanding requires a big effort. Typical example how to support the interviewee's understanding was using a whiteboard and drawing a process or a system, as well as presenting diagrams and schemes on the projector screen. In general, as the literature suggests (Bryman, 2012), the main focus was on the interviewee's personal point of view on the system behaviour rather than widely accepted knowledge. A crucial factor for the success of such technique of interviewing represented some extent of listening skills, to keep the interviewees engaged during the interviews. In total 15 participants have been interviewed in the research project.

2.3.5 Sampling

The sampling methods used for the purpose of the research project entails purposive sampling, the sampling widely used in the qualitative research that is conducted with a direct reference to the research questions (Bryman, 2012). The research questions in this research give some indications of the first samples in the data collection process, directing the researcher to the sample of context, in particular, Powertrain Attributes team and documents used internally within the team's operations. That indication offers the researcher to enter the context created by social actors performing the process of balancing powertrain attributes manually on daily basis. Subsequently, the initial participants were identified and observed in their everyday working life. In the later stage of the data collection process, the technique of snowball sampling was employed. Since the main purpose of the case study is capturing individual's tacit knowledge, it is hard to identify respondents for primary data collection without a direct connection. As "the method is particularly applicable when the focus of the study is a sensitive issue, possibly concerning and relatively private issue" (Biernacki and Waldorf, 1981, p. 141), snowball sampling finds perfect utilisation in this research. The initial group of participants proposed other participants who are part of different contexts, to be observed and interviewed. These participants were represented by individuals with more detailed knowledge about areas that lead to the research questions being asked. Those individuals were normally working within other business areas, yet close to the powertrain attributes team operations. Furthermore, participants initially proposed suggested other participants, and so on. An important part of the snowball sampling was the introduction to the new participants, which was done by those who proposed the new ones. This step opened communication channels with the new individuals and helped the relationships between the researcher and social actors to be established. In the course of the whole process, participants suggested various documents be examined, resulting in a great input for the data collection process.

2.4 Secondary data

The secondary data in Powertrain Attributes case study serve for creating structures of real physical systems (made from single components such presented in chapter 6) in the modelling environment. The data represents technical information earlier collected by Volvo design engineers and routinely kept in the official organisational electronic data archive. The data are stored digitally in the organisational cloud storage, forming a huge database of the organisational knowledge. A crucial task for the research is locating relevant data sources, as a distinct type of data are located on different database platforms. Once a data source was located, further consideration was necessary to secure the data suitability to the research project. It forms another important aspect for collecting the secondary data, assuring that the particular information is relevant for the research. The database includes many outdated visualisations and documents, and the research has to be based on the latest solutions. It is a difficult task to do for researchers from outside the organisation, as they do not have a relevant knowledge of particular systems. Therefore, identifying relevant functional data is challenging process permanently discuss with professionals with extensive experience about the product development process. At the latest stage, the evaluation of the data quality takes place, as the data has to fulfil certain criteria for a satisfactory scientific level of the research.

The main source of secondary data in this project implies Word documents, Excel sheets, PowerPoint presentations and CAD models of a whole vehicle. The vehicle is visualised using CAD technology, allowing a possibility to open each component separately as well as display more components together. The 3D models of the components are opened via product lifecycle management (PLM) software used across the organisation. The using of the database allows the researcher to present car components in setting standards, such as correct naming, numbering etc. Furthermore, it also helps to create a holistic view of the system functionality. Other forms of secondary data are miscellaneous documents found in the organisational clouds. These documents include administrative records such as official reports, informal meeting reports, presentations and many others.

2.5 Primary data

The primary data for the purpose of the research project represent system behaviour and context behind the operations within product development process. The data were acquired by unstructured in-depth interviews with professionals at the functional level such as powertrain attribute leaders, NVH engineers and individuals representing coordinating roles between those. Once the system diagrams were created on a component level, the input from individuals interviewed was registered. Such process has eventually resulted in the complete diagrams that capture the behaviour of changes within the components. An excellent presentation of the research and secondary data collected prior to the primary data assured an interviewee’s understanding of the research project, therefore, the relevancy of additionally collected data was not an issue as the interviewees had a clear sense of the desired result. Given their experience, they knew very well what input is necessary to conclude on the research questions asked.

2.6 Research ethics

2.6.1 Privacy

All participants observed, interviewed and recorded during the research project are under a high level of anonymity. The dissertation reports disclose just general roles such as “engineer”, which are not identifiable by people external to the organisation. In the same manner, individuals within the organisation are not able to track participants who are identified under general role titles in the research report. All research participants have been informed about information being published in the report prior to interviews and observations. All opinions of participants are anonymous. At the same time, all concerned participants have been offered to review the report before submitting to Chalmers University of Technology and Northumbria University. Therefore, the research project has not put anyone in a feeling of disturbance, unease of harshness.

2.6.2 Commercial confidentiality

The concerns related to commercial confidentiality have been discussed in the course of the entire research project. The main part of the discussion has been addressed to Volvo Car Corporation organisational members who are competent to indicate which information should not leave the organisation. Such roles include senior engineers, technical experts and managers with extensive experience and awareness about diversions between a general practice and company’s competitive advantage in the technology and product development process. Through the dynamic process of confidential adjustments, the report has been written without any reference to potentially confidential data. Eventually, an internal council that serves the purpose of the commercial confidentiality reviewed the areas with a possibility of confidential data disclosure. Such endeavour assures that no confidential information is disclosed to the outside world.

2.7 Research sustainability

The researched project has been conducted with a high aim to reduce the carbon footprint of the activities performed. White board has been used to create sketches of ideas instead of papers, if necessary recycled papers were used for making notes. The records were recorded to an offline device using reusable cassettes, which for most individuals crossed the ending point of their lifecycle. Prolonging the lifecycle of outdated cassettes reduces carbon footprint at a new device does not have to be produced and moved around the world. Moreover, a bicycle has been used to commuting to the Volvo Car Corporation site instead of public transport or personal combustion engine vehicle.

3 Related works

Technologies in all types of industries are being developed and knowledge to some extent continuously lost. Liyanage et al. (2009) regard knowledge as the most important resource of economies of today due to fear of its loss. According to Argote and Miron-Spektor (2011), knowledge transfer gains significant importance across organisations mainly due to work force retirement, work distribution, globalisation, international relationships, mergers, and more. Olaisen and Revang (2017) list knowledge as a crucial resource in a global project environment where awareness of circumstances and context plays an important role. Therefore, scholars around the world introduce various approaches in capturing and reusing knowledge to increase the intellectual property of organisations. According to Ringen et al. (2016), many companies have introduced a number of tools to improve organisational learning and knowledge management practices, without being straightforward enough to generate innovative ideas. For that reason, knowledge management in the traditional product development has a big attention as well as in the New Product Development (NPD). As some suggest the majority of knowledge in the NDP process can be categorised as tacit knowledge (Ringen et al., 2016), others may argue that it is not just tacit knowledge within NPD that must be handled in a more efficient way. Explicit knowledge might come second when discussing the ability to innovate, but equally important to well-handled in order to keep track of functional interdependencies in both NDP and also traditional PD. Generally speaking, a desire of many scholars is to express tacit knowledge in an explicit way, therefore a number of models explain the process of knowledge transformation.

3.1 3-T framework

Carlile (2004) introduced the 3-T framework proposed to be used for managing knowledge in an environment where innovation is desired, presented in the early stage of vehicle development to illustrate its application. The work uses known and novelty as a useful context in order to "explore the negative consequences of the path-dependent nature of knowledge" (Carlile, 2004, p. 555). Using such context allows practical and political mismatches to be specified. As the figure 3.1 indicates the 3-T framework describes three complex boundaries – pragmatic, semantic and syntactic (Shannon and Weaver, 1949, in Carlile, 2004) and three progressively complex processes – transformation, translation and transfer of knowledge.

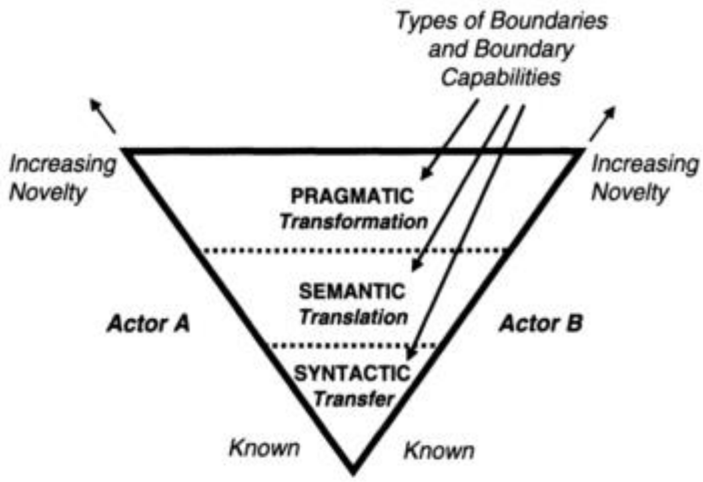


Figure 3.1 PD Knowledge framework (Zammit et al., 2016, p. 442)

As Le Dain and Merminod (2014) explains in their work, transferring specifies differences and dependencies, translating develops common meanings to reduce interpretation gaps and transforming helps to problem-solve by creating new knowledge. Such description can be also perceived as misleading because transforming itself does not create the knowledge but just shares between the actors. However, Le Dain and Merminod also clarify that the 3-T framework brakes down the process of knowledge sharing into the three subprocesses: transferring, translating and transforming. Once an understanding is developed, the process of knowledge sharing is empowered and knowledge certainly contributes to solving complex problems.

3.1.1 Transferring knowledge

At the bottom level of the 3-T framework, knowledge between various actors meet at the syntactic boundary. At this boundary, the knowledge is being moved between a sender and receiver (actors). A common lexicon identifies differences and dependencies between, helping the knowledge to be transferred from one actor to others (Le Dain and Merminod, 2014). Assumed that the knowledge is known to the common lexicon shared between the actors, the process of transferring the knowledge does not tend to be problematic (Carlile, 2004). However, when the level of unknown knowledge is being increased, one can argue that the common lexicon is not able to exchange the knowledge between the actors as more significant misinterpretation can be created. In such case, an escalation to another level that considers more novelty knowledge is crucial. This point can be illustrated same as two individuals speaking different languages having a just limited common pool of dictionary. Once the boundary of common word pool is passed, they won't be able to speak anymore.

3.1.2 Translating knowledge

In the middle level of the framework, the semantic boundary is incorporated. At this level, the escalation from the syntactic boundary is accompanied by a translation of the knowledge that has not found same "language" in the common lexicon. As Carlile states "the transition from a syntactic to a semantic boundary occurs when novelty makes some differences and dependencies unclear or some meanings ambiguous" (Carlile, 2004, p. 558). It's clear that the process of translation serves either for the purpose of extending the capacity of the common lexicon between actors or providing them with tools through which the knowledge can be interpreted. As a result of that, the level of the misinterpretation generated by interpretive differences between the actors is reduced (Le Dain and Merminod, 2014). The subprocesses of knowledge sharing can be understood as progressive. Interpretation gaps in the process of transferring have to be found and consequently fixed in the process of translation. If there were no gaps, one can assume that the knowledge could be shared at the bottom level. Going further in the process, the interpretation gaps are reduced and the knowledge is translated. Considering that interest of all actors is the same, the knowledge can be considered ready to share again. However, what if the nature of knowledge, interest and stake of the actors within a cross-functional environment is different. Then, the third subprocess has to be employed.

3.1.3 Transforming knowledge

In the top level, the pragmatic (political) boundary is found. Some can point out that this is the most important level in the majority of organisations, and it is most probably true. As can be observed in the 3-T framework visualisation in figure 3.1, is it the highest level of novelty where the subprocess of knowledge sharing finds its place. The level where cross-functional knowledge streams meet together, acting as a critical part of s fully sustainable mechanism as knowledge which is transformed can be transferred and enter the cycle through the bottom level (Le Dain and Merminod, 2014). Such process is visualized in figure 3.2.

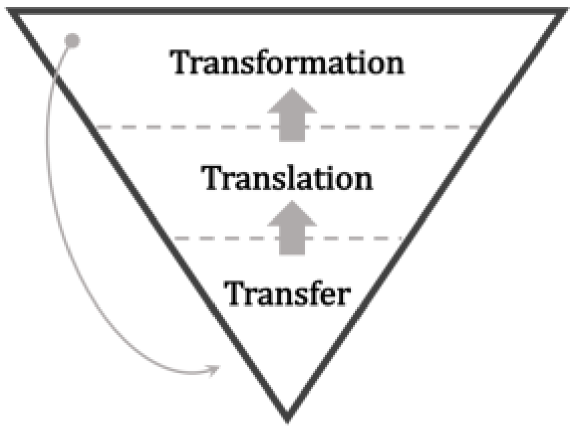


Figure 3.2 Visualisation of the 3-T model sustainable cycle (Le Dain and Merminod, 2014)

The transformation takes place when the novelty generates outputs with different interests between actors but yet same and/or common dependencies. On that occasion, actors with function specific knowledge share this at the boundary, resulting in an access point to domain-specific expertise. The framework recognises that in order to make knowledge being transformed from some domains to others, willingness to invest from actors who possess the knowledge and willingness to learn from the one on the opposite side of the boundary must be present. (Carlile, 2004)

Only then a successful transformation can take place, allowing the knowledge to enter the sustainable loop again and being shared in form of transfer at the syntactic boundary (Le Dain and Merminod, 2014).

3.2 Process of knowledge query and recommendation

Zhen et al. (2013) conducted a research project that facilitates KM tools for knowledge acquisition and sharing. In the paper, two basic channels defined as knowledge query and knowledge recommendation are presented. Most of the readers would assume that the two channels are usually found in informal KM process as the knowledge has been always requested from individuals, and also recommended to others in a situation which has been encouraging the knowledge owners to share without a query. As Zhen et al. (2013) clearly states, the knowledge query has been a basic element for all kinds of KM tools acting also as a basic component of the channel of knowledge recommendation. An argument can arise as opposite of a knowledge query should be considered as a "knowledge response", which has been delivered based on querying a specific area of expertise. To answer the traditional knowledge query, a process of capturing, storing and sharing knowledge across the organisation must be well-handled.

3.2.1 Knowledge query and request

Zammit et al. (2016) researched about a way how to capture and share employees knowledge in a big original equipment manufacturing company operating in the UK. In their research project, a knowledge framework describes capturing, storing and sharing knowledge with relation to knowledge queries and knowledge requests. Such model allows building upon already existing knowledge (query) as well as start impulses for non-existing knowledge (request). In general, such combination represents a solid process, which allows "query the readily available knowledge; if this is not found, a knowledge gap is identified, activating the knowledge Capturing task by a knowledge expert and, finally, the learning process" (Zammit et al., 2016, p. 442). Such attitude towards the KM is a natural way that has been probably adopted by many institutions but mostly in an informal way without forming a rigid structure. Some might suggest that a challenge will arrive with the transformation of such framework into a standard being applied by organisational members in the everyday practice. For better understanding, a visualisation of the model can be seen in figure 3.2.

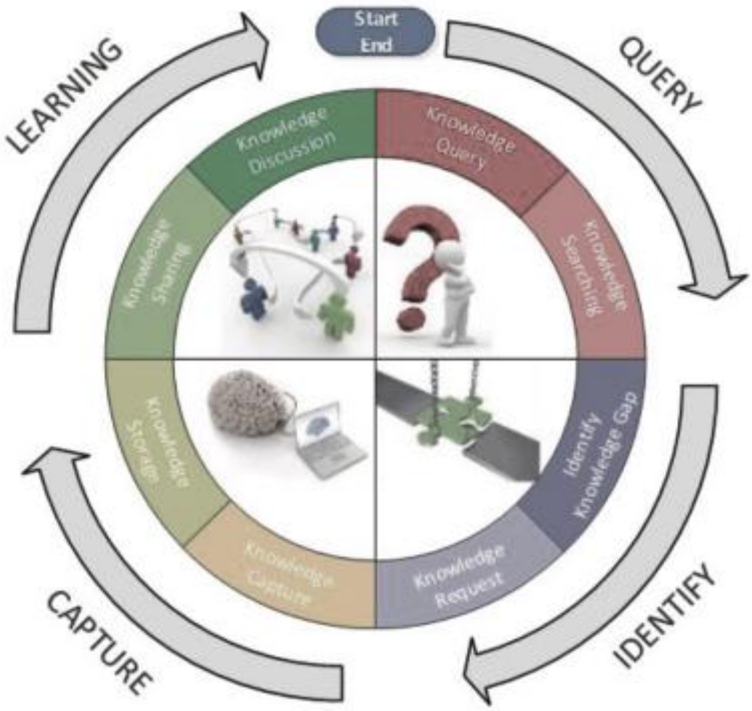


Figure 3.3 PD Knowledge framework (Zammit et al., 2016, p. 442)

The model divides the process of the KM and organisational learning into four phases. In the first phase, the query is the starting point being represented by the process of knowledge search. The main purpose for the first stage is to allow the knowledge seekers (users) to track the knowledge they are looking for and expand the knowledge content by opening a discussion with experts (providers). The second phase, identify, describes a process which takes place if the knowledge queried is not available in the database. In this phase, after a knowledge gap is identified the knowledge missing in the system is requested through a formal request form. That initiates a direct contact between knowledge users and providers. Once a request is submitted, an administrator responsible for the request double checks if the knowledge is already in the database, if not then assign a suitable provider to kick off the knowledge capturing process. It should not be a rule that a knowledge request is put in place just by users as providers can identify gaps as well. In the third phase, capturing, the provider assigned to the knowledge request either possess the knowledge or acquire the knowledge using various resources such books, the internet, manuals, etc. After the knowledge is acquired, a knowledge contribution plan is made. Then, the plan is approved by the requesting administrator and stored in two chosen formats, a video or a voice story. In the last phase, the knowledge request has been addressed and the knowledge is shared with relevant knowledge users in the two mentioned formats. At the very last point, a discussion about the knowledge contribution can take place. (Zammit et al., 2016)

The presented framework shows one of a possible way how to track knowledge and also acquire new knowledge that is not available in the organisational knowledge base. It represents logical flow that results in a continuous loop, making it a fully sustainable process to handle the KM. However, the two proposed formats for knowledge storing, videos and voice stories, can be seen as a limitation that addresses only tacit knowledge. As explicit knowledge is usually transferred through in forms of data, specifications and formulas (Nonaka and Teece, 2001), one can assume that it is difficult to transfer such type of knowledge in videos and voice stories. Another limitation is incorporated in the user interaction that is necessary from the very start. A query has to be always put in place by a user, otherwise, the process never starts. Thinking of an organisational knowledge database that stores videos and voice stories, why does the knowledge have to be queried or requested will be always a question to be answered. Therefore, another level can be represented by implementing a process of knowledge recommendation.

3.2.2 Knowledge recommendation

In the dimension of knowledge recommendations, nor a query neither a request have to be risen to initiate the act of knowledge recommendation. As the research group identified, using a traditional approach of the knowledge query might not lead to a high level of innovation as engineers of today have to think outside the box in order to be able to problem solve (Zhen et al., 2013). Naturally interpreted, such approach can deliver unexpected ideas to organisational members, therefore, increase the number of ideas within product development activities. Moreover, querying knowledge can be time-consuming compared to knowledge recommendation. As an effect of that, the function of knowledge recommendation has to get further attention. One option of how to find a balance between querying and recommending knowledge is an extension of the query framework. Bellow presented KM framework incorporated queries as well as recommendations. The queries are created based on requests for specific knowledge, such requests are created by users searching for knowledge based on keywords, and being extracted from the knowledge repository through the knowledge query portal as shown in figure 3.4. The function is managed by a query log, which represents history records of all knowledge requests and has the primary function of updating users on the status of their knowledge requests. Having well-managed query function the recommendation extends the ability of the framework to support organisational members in thinking outside the box. According to Zhen et al. "Knowledge recommendation can act as a supplement way for the traditional knowledge query in the KM tools" (Zhen et al., 2013, p. 884). The extended KM tool framework presented in figure 3.4 has a sophisticated way of handling the function of knowledge recommendation, which serves mainly to those who perform specific design works in the product development.

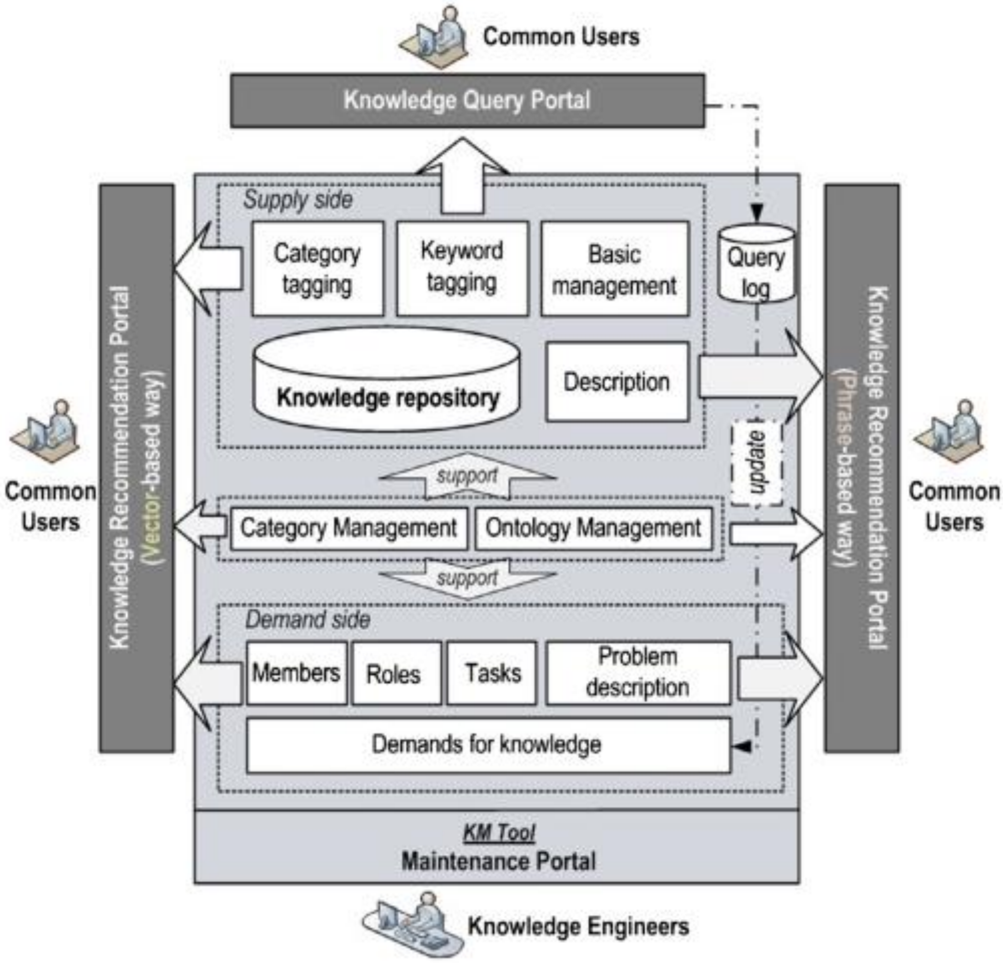


Figure 3.4 Extended KM tool framework (Zhen et al., 2013, p. 886)

The function of knowledge recommendation involves two groups of actors. First, common users represented by all organisational members such as engineers, designers, managers and others who are primary users of knowledge query and knowledge recommendation portals. Second, the experts who are principal owners of the process and responsible for running a maintenance portal referred as knowledge engineers. The framework splits the function of knowledge recommendation into two sub-functions both representing the key techniques. First a vector-based, and second a phrase-based. The functions do not require direct users input neither any search criteria as the “KM tool can supply the users with some knowledge resources that may be potentially useful for them” (Zhen et al., 2013, p. 886).

To supply the common users with relevant knowledge, matching between the knowledge demand and knowledge resources represents the biggest challenge in the overall KM solution. Important to mention is that in this framework, the knowledge demand does not represent a knowledge request, but is generated based on a knowledge request that has not been addressed in the knowledge repository. According to Pera and Ng (2013, in Zhen et al., 2013) recommendation systems normally use similarity based matching and popularity analyses to perform efficient matching between a demand and knowledge resource.

The vector-based function proposed by Zhen et al. (2013) uses a vector method for measuring similarities. The vectors are assigned to keywords on the knowledge resource on the repository side and also on the knowledge demand side. Every element in the vector exhibits a degree according to which knowledge resources and demands belong to a certain category. A match between demand and available resource is a result of the degree of similarity calculated by a mathematical formula. The vectors used in the calculations are now static as they change with the users' activities and available knowledge resource in the repository.

A difference in comparison to the vector-based function, the phrases-based function describes knowledge resources and demands in some structured phrases. However, it keywords still plays the main role in this approach. In a typical setup proposed by the framework, demands are described in the phase structure "adjective + noun + of noun". In the engine development process where a diesel engine consumes too much oil, it can be a phrased as "excessive oil consumption of diesel", whereas the combination of two words "oil consumption" represents the problem. Resources are to be described in the phrase structure "verb + noun + of noun". With the same problem in the engine development process, a phrase "decrease oil consumption of diesel" can merge in the knowledge resource repository. (Zhen et al., 2013).

Such approach can be considered having a limited efficiency. If a user wants to reach knowledge resources, he or she is still required to raise a demand for a similar set of knowledge either in the vector-based and phrase-based approach. In the ideal framework, the system knows the interrelations itself and the knowledge are "truly" recommended to the users without a necessity of any interaction with the demand side. In the reality, it means that the demand is created by the system itself rather than by users. Therefore, this work suggests a framework which will be based on the content in the database, supported by a system that is to be able to handle to process without any significant interaction with its users.

4 ORGANISATIONAL CHALLENGE

4.1 The dynamic of automotive industry

After getting over from the recession slump that started in 2008, the car sales raised especially in North America, Europe and Asia in 2015 (Strategyand.pwc.com, 2015). As presented by the PwC strategy report, the most challenging forces driving the change in the automotive industry are a shift in the consumer demand, expanded regulatory requirements, safety and fuel economy. The driving forces for industry transformation make pressure on car makers to introduce new technologies related mainly to safety and fuel efficiency, as many of highly regulated factors are connected to those two. In order to meet the market requirements in the next decades, an upcoming transformation is the most dramatic since the Ford T model was introduced in the United States in the 20^{th} century (Strategyand.pwc.com, 2016).

In the car manufacturer practice, it means that the development process will become more complex than it already is today. New development challenges arise as well as current standards have to be updated as a result of increasing complexity. As the matter of fact, it is not just the scope that will increase, equally important is shortening the development time that will help to respond effectively to the agile market environment and cut down developing expenses. It is no more possible to rely on outdated project management processes developed in past decades, management groups rather have the vision to implement new processes that will help to increase the efficiency by running the development process digitally. Processes within the vehicle development phase might be reliable and functional, however, some may argue that they are not sufficient for surviving in the future market environment. Many of those processes have been efficient at the time when the manpower was the major resource, but in the age of digital technology, the implementation of digital solutions is crucial for success. It tends to be more complex in organisations that already have established processes, as many organisational members tend to stuck in inertia (Wit and Meyer, 2014). Therefore, new competitors in the car industry might have a unique position, as they have created processes from the scratch and built whole organisations on digital platforms offered by hi-tech software companies. However, current situation indicates that vehicle manufacturers with long tradition face a huge challenge to undergo a complex transformation that moves them towards the digital world. Getting to the point when the information flow within the product development process is transparent and agile will allow manufacturers to develop vehicles over a shorter period of time, therefore, save a lot of resources through the development and test phases. The transparency and efficiency can be reached by implementing digital solutions that manage organisational processes and offer a transparent user facing platform, which can be understood but a wide range of organisational members.

4.2 Volvo Car Corporation

Volvo Car Corporation is a premium car manufacturer headquartered in Gothenburg, Sweden. The company has a long tradition, being established in 1927 (Volvocars.com, 2016b) allows it to build competitive advantage on accumulated experience. In 2010 Volvo Car Group was acquired by Zhejiang Geely Holding of China, when an organisational transformation has begun. Nowadays, the corporation employs more than 30,000 people worldwide (Volvocars.com, 2016b). Selling first time more than half a million cars in 2015, from which has more than half of its retail customers in Europe (Volvo Car Group, 2016), the future looks very promising. It also shows a great opportunity for the car manufacturer to grow in global markets, especially in China and the US. As a result of the existing success, the organisation wants to reinforce its global market position by being the world's most progressive premium car brand, and boost sales up to 800,000 units annually (Volvocars.com, 2016a).

In order to do that, the rapidly changing market environment has forced the Volvo Car Corporation to undergo a significant transformation. The transformation that has taken place within research and development process, but also in building product portfolio on modular platforms (Volvo Car Group, 2016). Yet the transformation is not finished, the group's CEO Håkan Samuelsson encourages the organisation into the second phase of the global transformation (Media.volvocars.com, 2016). As the second part of the transformation, the car manufacturer aims to shorten the car developing process into less than two years, precisely to 20 months long period (Morey, 2014). It will help planning units to challenge future market needs, as the time gap between project initiation and product launch will become shorter. Such aggressive change in the developing process requires introducing new technologies that will increase the efficiency of project management practices. One of the aims in the move is to focus on capturing, sharing and reusing organisational knowledge. The management vision is to turn into a knowledge-based organisation. Many options arise when discussing capturing and reusing accumulated knowledge. However, once the knowledge is found and captured, the second step on the way is to communicate it and make it easily accessible for all individuals across the organisation. In the case that the particular knowledge is not captured, efficient tracking of individuals that own the knowledge is desired to establish an agile knowledge transferring channel. It can be done by implementing a digital solution that visualises the behaviour of the developing process and car components through an intuitive system architecture. Such architecture should be able to capture, share and communicate knowledge as well as create a database of roles within the organisation connected to a particular set of knowledge. With this in consideration, a possible option to create the system diagrams is to look at the problem from the system engineering perspective. Many professionals across the organisation agree that the acceleration of the developing process can be done by introducing digital tools that allow to learn and communicate systems behaviour related knowledge efficiently.

4.3 Powertrain Attributes

The Powertrain Attributes team is a recently established unit within research and development, supporting operations of Powertrain department. The unit was created with a clear goal to coordinate activities between design engineers, powertrain competence centres and concept leaders and to manage powertrain attributes balancing process. Since the beginning of its operations, the team has identified bottlenecks in the attribute balancing process that have resulted in delays in the vehicle development phase. The complexity in communication between departments, significant delays arriving with searching for responsible individuals and difficulties in sharing knowledge have escalated developing process into complicated phases.

The Powertrain Attributes Team (PAT) works with three clusters of most significant attributes that dominate in the powertrain development process, namely noise, vibrations & harshness (NVH), emissions, and performance & driveability (P&D). The main function of the team is to bridge a gap between technical experts, design engineers and concept leaders. The role of technical experts is setting targets related to the technical specification of the vehicle functions. Such experts set these targets based on regulations, strategy and market concept. Then, design engineers develop a prototype design using computer aided technologies such as CAD and CAE. In the ideal case, engineers develop solutions that meet expert's requirements and then present the solution to concept leaders. In the next stage, the concept leaders make decisions. The decisions are typically compromises between time, scope and budget in order to meet the targets set in the first stage of the development process. After the decisions are made, the industrialisation phase takes place. First prototypes and test vehicles are rolled out during the industrialisation process, and as might be expected many shortcomings in the first prototypes are found. At this point, the operation of the PAT is usually employed. An example that embodies troubles emerging at this point are difficulties with finding a balance between the three main attributes that represents noise, vibrations and emissions.

The PAT consists of attribute integration leaders, who are allocated to three functional areas (NVH, P&D and emissions) with a responsible leader for each area. In daily practice, attribute integration leaders receive a request asking for a solution that either increases or decreases attribute's parameters. At this point, the leaders start to contact experts and engineers in different R&D units often not even knowing who is the one responsible for particular components and functions. Therefore, they normally start to contact people that they identify as relevant to the particular issue and then keep on using snowball method. This method has big time limitations, as in some cases it might take even weeks before the leaders get to competent individuals. Once the competent sources are found, the attribute integration leaders have to do the whole (original) process again, simply bridge the three parties again (technical experts, design engineers and concept leaders).

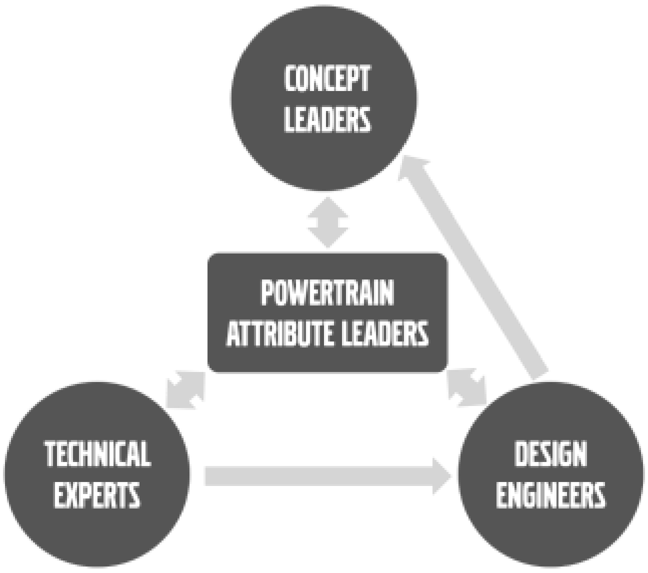


Figure 4.1 Visualisation of Powertrain Attribute Integration Leaders role

Particularly speaking, it means asking for new targets or confirming the targets by experts, urging design engineers to find new solutions, and presenting the solutions to concept leaders in order to support them in the decision-making process. In the normal practice, the solution is presented through a simple decision matrix created in Microsoft Excel. Finally, the attribute team lets a leader make a new decision on the component and its function. The most common problem with implementing reworked solutions is space in the car assembly (packaging), as once the car is build components are precisely organised. As one might expect, solutions that increase the performance of functional systems have mostly bigger dimensions and require more space. Equally important is the interaction with other attributes, as in most cases to fulfil requirements of one attribute, another attribute is less acceptable, i.e. noise level and performance are often in contradiction. On the top of that, the process itself takes weeks. Regardless of the huge time delay, considering the manufacturing of new testing vehicles and doing tests over again increase the expenses in the vehicle development process (VDP).

In the ideal VDP, the existence of the unit would not be necessary. However, it is not just the testing phase when the issues come out. As the number of components and functions complexity within the VDP increase over the time, many issues emerge even before the industrialisation phase takes place. This happens during the design stage when sophisticated CAE calculations are under way. The misunderstandings are created mainly because design engineers are not aware of the impact of their actions on other components functions. As today the knowledge about systems is stored in decision matrixes, meeting reports and other documents available on the internal cloud. When the wisdom is stored this way, it is difficult to find it and extract.

4.4 Functional Disposition

Besides the urgent need in the PAT, the unit is not the only lonely island that is not effectively connected with others in the R&D organisation. Functional Disposition (FD) is another unit that calls for an interactive digital tool that will help the teams communicate and learn interrelations within the system. The primary mission of FD is to create, configure and control functions in the car systems. The vehicle functions are broken down into single functions, each managed by a function owner. One of the typical function examples is a cruise control, which is defined as customer function. The well-known inputs for this function can be observed by each driver. It might be as simple as seat belt fasten, minimum speed and other various inputs as the speed set by the driver, which is defined as a product function. At the functional level, this information is normally provided by sensors accommodated in the car and communicated by a software system. On the other hand, the function gives a certain output for other functions such as engine, head-up display and other systems. The number of product functions that interact with other single functions can be incredibly high. The function owner has to know which inputs and outputs (signals) are relevant to his or her function, to be able to design the function is his or her ownership.

In the real practice, as the number of signals connected to single functions is huge, the function owners often don't even know to which extent their changes in the output signals affect inputs for other functions. At the same time, they are not aware how many input signals that they use have been changed. Nowadays there is a certain extent to which function owners control this changes, mostly with sharing them in Microsoft Word documents. However, the practice shows that the process is digital unfriendly and time-consuming, having significant limitations in showing interactions and being synchronised at the organisational level. Moreover, if the FD team wants to reveal connections between customer function requirements and product function signals, digging into documents without knowing about the interrelations is found as a big challenge for knowledge tracking. Additionally, function owners have to rely on their past experience and make assumptions. As one can imagine, it is neither reliable nor sustainable attitude in the time when the number customer functions in cars are increasing with incredibly fast pace.

4.5 Activity Planning

The desire of going smart and digital is not just at the technical management level, but also in the fundamental project management process such as planning. One part of the VDP that the Activity Planning (AP) unit within Powertrain department is responsible for is engine calibration. The main challenge for AP teams is to observe activity regularities and activities that perform a same set of actions. At this time, the unit claims that lot of double work is done as they are not able to see which activities perform the same calibration process. For example, a tool that allows the team to map the process of engine calibration will help individuals to find synergy in the wide range of activities.

By doing that the team will improve their understanding to the activities and interactions between them. Using the OPM the unit will optimise the planning process in the future operations by proper sequencing of activities and prioritising them. Such optimisation will have a significant impact on the cost and time frame estimation.

Nowadays, the team is considered as most advanced with system engineering approach in the organisation, working on diagrams that represent activities allows the team members to increase the efficiency of knowledge sharing in the planning process. However, as a rigid process is not fully implemented yet, the operations still rely on an outdated process. It means that senior engineers, the ones responsible for project plans creation, don't have the detailed knowledge about activities interactions and overlaps. Moreover, the information about interrelations is stored in Microsoft Excel sheets without any intellectual connections. That way of conducting planning process creates extra costs as some activities might be performed more than once.

4.6 Sign-off Process

The unit responsible for functions at the complete vehicle level, so-called "sign-off process" requires an efficient process for improving knowledge management practice to manage its operations too. In the standard operations, the team starts with advanced engineering system where its members define single systems and its function. Once that is done, function responsible move to concept phase, where they study the way how the single functions within the systems interrelate in order to share knowledge. At this time, it is impossible to see all the interactions. For example, if someone wants to reduce fuel consumption, it is usually accompanied with friction reducing. However, if the friction in the engine is reduced less heat is generated, it can result in a lack of heat in the passenger compartment. Such event is a problem as extra systems (i.e. heater) have to be added in the very late phase of the developing process. Moreover, such physical system has always additional impact on other systems and their functions. Because on many occasions, attributes and functions that are extracted from requirements lead to the same components (physical systems), there is a desire to develop a tool that will allow the team to have a clear view over functions interrelations at the complete vehicle level.

These days, if the responsible leaders in sign-off unit want to know how a system interacts with others, heavy teamwork is employed. The leaders even do not know individuals who own the systems and their competence. It results in meeting many people from different functional areas and then discussing functions within their areas of expertise. Sometimes, a solution might be found, but not always. The unit uses some digital tools that help the leaders to reveal interactions between functions, however, such tools are not well synchronised with other functions that are developed across all the R&D departments. For instance, a PLM software Teamcenter is used for defining requirements for the sign-off process, but might not be used in other technical areas.

Besides the lack of relevant information in the software solution, using that tool brings many limitations that slow down the ability of desirable sign-off process.

4.7 Call for a solution

The empirical research through the powertrain teams has revealed desires to increase the efficiency of the knowledge transfer in the vehicle development process. Significant misinterpretation generated in the communication between individuals represents a pinpoint as well as tracing competent individuals. As each individual expresses in a different manner, the major part of misinterpretation is created within cross-functional areas. Therefore, the initiative for implementing a conceptual modelling system for representing systems and processes interrelations graphically was born. The PAT believes that capturing engineer's expertise about attributes interface in an intuitive manner will help developing engineers in their part of the VDP. The FD unit wants to introduce a sustainable process, which will allow to create and store content easily, and communicated in real-time. Furthermore, FD team desires the behaviour, structure and details of the functions system to be projected visually. Current process using system engineering diagrams works for content creating, however, there are limitations in effective post-processing and synchronising across the whole R&D department due to the high complexity. The AP team desires same functions as the two units, furthermore being able to export the information in the OPM to Microsoft Office tools, what allows them to plug-in the solution to other established processes. Once that is done, there might be a cycle plan in the background allowing others to discover activities from the top perspective. Similar desires come from the unit responsible for the sign-off process, as the unit looks for a solution that let them know how the changes in some functions at the complete vehicle level affect other functions.

The very reason for including other units then stick with a primary focus to PAT is to develop a reader's understanding to the general problem, which reveals that the same top functionality will bring benefits to more parts of the organisation. On top of that, the desired solution has a huge potential to save resources in the testing phase and speed up the whole VDP. Furthermore, management expects that the wisdom shared and communicated with a digital tool will be reused as many times as possible. Once a common tool is successfully developed it can be implemented in other functional departments, therefore, increase the intellectual assets of the whole organisation.

5 OBJECT-PROCESS METHODOLOGY (OPM)

The OPM tool is a unique system modelling paradigm proposed to support the knowledge management practice by Volvo Car Corporation's experts. The tool was developed at Technion, Israel Institute of Technology in Tel Aviv, Israel and Massachusetts Institute of Technology in Cambridge, the USA by Prof. Dov Dori and his partners. OPM is a fundamentally simple tool that represents objects – things that exist and processes things that transform and happen to objects (Dori, 2002). An object reflects what a product is and a process expresses what the product does. According to Dori representing a system with the simple idea that allows integrating structure, function and behaviour of the system in one model. Many theories across the industries such are software design, mechanical design and civil architectural design recognise the value of modelling systems processes in parallel with objects (Dori, 2016). Some argue that "while the methodology eliminates the challenges of managing multiple views of a system architecture, it is a descriptive approach and does not explicitly address the life cycle properties of a System (Kilicay-Ergin et al., 2016, p.1). However, in the case study of balancing powertrain attributes, this limitation doesn't play an important role as the goal of the pilot project is to research a possible way of capturing of system knowledge. In that sense, the project builds on the main advantage of the methodology, representing the system simultaneously in formal graphics (Object-Process Diagram) and natural language (Object-Process Language) in natural English. The two ways of representation are interchangeable, providing exactly the same information and allowing a user to engage visual and language interpreter in order to increase the ability to understand (Dori, 2016). Furthermore, the creator emphasises that the way in system representation is easily accessible for non-technical stakeholders, enabling them to take part in critical stages of system architecting and development. As the result of the simplicity, the OPM is widely used in architecture generation, mapping processes to form relations between system structure and its function (Kilicay-Ergin et al., 2016).

The Object-Process Methodology is compatible with ISO 19450 Publically Available Specification titled "Automation systems and integration – Object-Process Methodology". The ISO 19450 PAS was adopted by the International Organization for Standardization (ISO) in December 2015. ISO introduce OPM as a compact conceptual approach. Language and methodology for modelling and knowledge representation of automation systems. According to iso.org (2016), the OPM "serves as the basis for model-based systems engineering in general, including systems architecting, engineering, development, life cycle support, communication, and evolution". Considering the description in ISO database, the ability to use the tool as a basis for evolution is particularly in favour of capturing knowledge and representing it through the system models.

In this case study, the methodology is desired to represent certain physical car system and describe the behaviour of the system and its attributes through OPD and OPL.

Creating system maps requires knowledge of fundamental OPM entities and links that connect them. The main idea is to create system OPDs, then identify related attributes among the technical experts, and in the end, extract the relations between a system and its attributes from OPL in explicit form. To understand the methodology, basic explanation of the main elements is provided in following sub-sections.

5.1 OPM entities and links

OPM is based on three types of entities: objects, processes and states, with object and processes being the top level blocks (Dori, 2002). Objects characterise things that exist, while processes yield objects, consume objects or change object's state. A procedural link can exist just between an object and a process. In general, procedural links express relations between objects and processes.

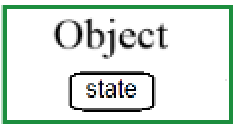
	Visual Representation	*Definition*	*Description*
Entities		An **object** is a thing that has the potential stable, unconditional psychical or mental existence.	Static things. Can be changed only by processes.
		A **process** is a pattern of transformation that an object undergoes.	Dynamic things. Are recognisable by the changes they cause to objects.
		A **state** is a situation an object can be at.	States describe objects. They are attributes of objects. Processes can change an object's state.

Table 5.1 OPM Entities (adopted from Dori, 2002)

	Visual Representation	*Link Title*	*Description*
Procedural Links		Agent Link	An object that manages a process is connected via agent link. The object is human not changed by the process.
		Instrument Link	An object that is required for a process to be done is connected via instrument link. The object is an instrument not changed by the process.
		Result/Consumption Link	A process can create (generate and construct), consume (eliminate and destruct) an object or change its state.
		Effect Link	A process affects an object in an undefined way.

Table 5.2 OPM Procedural Links (adopted from Dori, 2002)

On the other hand, structural links express relations between two or more objects or two or more processes. An object and a process cannot be connected with a structural link.

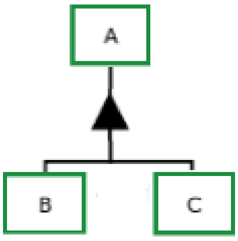
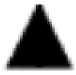
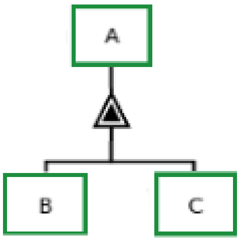
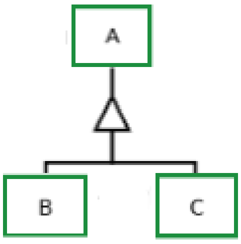
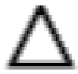
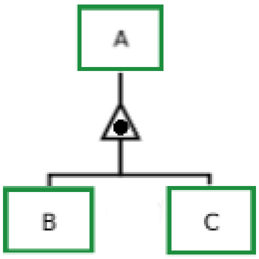
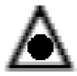
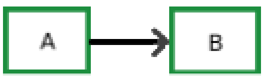
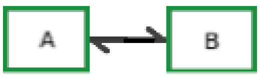
	Visual Representation	*OPL Sentence*	*Description*
Structural Links		**A** consist of **B** and **C**.	**Aggregation**  B, C are parts of the whole A.
		**A** exhibits of **B** and **C**.	**Exhibition**  B, C are attributes of A. If B is a process, it is an operation of A.
		**B** and **C** are **A**s.	**Generalization**  B, C are types of A.
		**B** and **C** are instances of **A**.	**Classification**  B, C are unique objects of class A.
		**A** relates to **B**.	**(Null)** Relations from a source object to a destination object can be specified with tag (Tagged).
		**A** and **B** are related.	**Bi-directional** Relations between two objects can be specified with tag (Bi-directional Tagged).

Table 5.3 OPM Structural Links (adopted from Dori, 2002)

5.2 Object-Process Diagram (OPD)

Diagrams are intuitive ways of expressing systems across many fields, as theories from past millennium suggest, "with diagrams the meaning is obvious, because once you understand how the basic elements of the diagrams fit together, the meaning literally stares you in the face" (Cook, 1999 in Dori, 2002, p. 13). The statement covers the main idea of the OPM. The Academic Dissertation example in figure 5.1 shows the basic form of OPD created in OPCAT II software. Objects with objects are connected via structural links as well as processes with other processes. Objects with processes, on the contrary, are connected via procedural links with the line of the OPM standards.

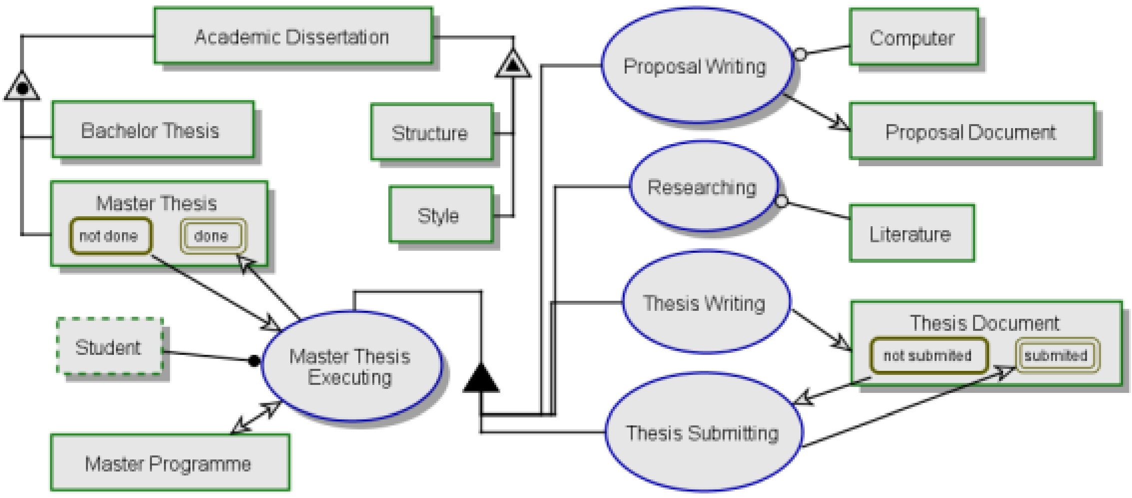


Figure 5.1 Academic dissertation OPD example

5.3 Object-Process Language (OPL)

The previous figure shows a simple example of system diagram. In order to enhance one's understanding of diagrams, OPM generates a textual counterpart of the OPM diagram (Dori, 2002). In other words, the OPL generator transfers the same information that is stored in the diagram into easy readable natural English written sentences. The example in figure 5.2 is language generated from the diagram above.

Student is environmental and physical.
Student handles Master Thesis Executing.
Academic Dissertation is physical.
Academic Dissertation exhibits Structure and Style.
    Structure is physical.
    Style is physical.
Thesis Document is physical.
Thesis Document can be not submited or submited.
    not submited is initial.
    submited is final.
Computer is physical.
Proposal Document is physical.
Master Thesis is physical.
Master Thesis is instance of an Academic Dissertation.
Master Thesis can be not done or done.
    not done is initial.
    done is final.

Master Thesis can be not done or done.
    not done is initial.
    done is final.
Bachelor Thesis is physical.
Bachelor Thesis is instance of an Academic Dissertation.
Master Thesis Executing is physical.
Master Thesis Executing consists of Proposal Writing, Researching, Thesis Writing, and Thesis Submitting
    Proposal Writing is physical.
    Proposal Writing requires Computer.
    Proposal Writing yields Proposal Document.
    Researching is physical.
    Researching requires Literature.
    Thesis Writing yields Thesis Document.
    Thesis Submitting changes Thesis Document from not submited to submited.
Master Thesis Executing affects Master Programme.
Master Thesis Executing changes Master Thesis from not done to done.

Figure 5.2 Academic dissertation OPL example

5.4 Reading OPD and OPL

The understanding of the OPD structure has not any particular reading order of the OPM symbols (Dori, 2002). However, the key for understanding to OPDs is based on three concepts. Firstly, the concept “flow of control” has to be adopted. To figure out what flow of control in OPM means, one must keep in mind that objects are needed for processes to occur. Dori (2002) divides process to pre-process and post-process objects. Pre-process objects are those that are required for a process to happen. On the other hand, the post-processes are those that exist because of the process existence. Objects can be affected, created or consumed. Once the pre-process and post-process objects are identified, the diagram can be read in designed order. Secondly, the timeline from top to bottom often gives a sequence of processes in which order they happen. Therefore, usually processes on top occur prior to processes on the bottom. T may happen that timeline order also follows a different order, however, the order is to be defined by the diagram designer. The general rule is to read OPD from top to the bottom, if two or more processes are aligned at the same high, they occur at the simultaneously as two processes in figure 5.3. Thirdly, object states often enable certain processes to occur. For instance, in figure 5.3 process accelerating requires different object state than breaking process. It means that just one process takes place, regarding the state of the object. In that sense, object states should be followed while reading OPDs, as it shows a reader the consequence of the conditions for relations.

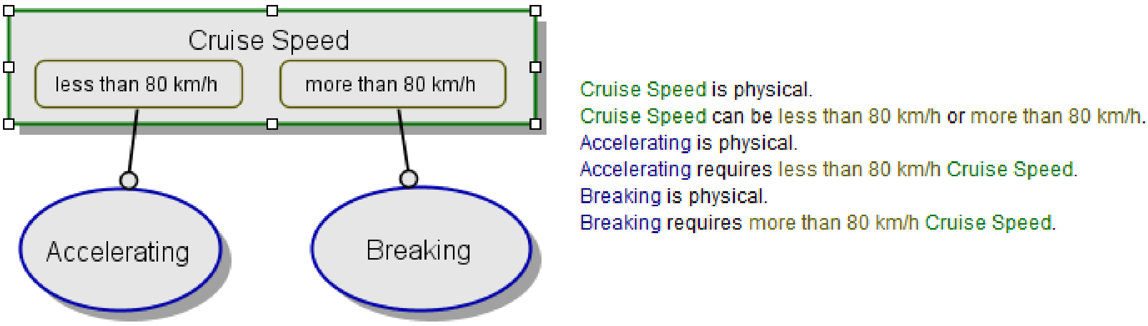


Figure 5.3 Cruise speed control system example

OPL is normally generated with object sentences at the top and processes sentences below. The main idea is that firstly, objects and their nature in the system is presented, later, the relations between them and processes is provided. The description of the relations between object and processes may emerge in two sentences instead in just one as one may suppose, however, it depends just on the software.

5.5 OPCAT

Nowadays, the only software that is fully compatible with OPM theory is OPCAT 4.0, developed by Enterprise Systems Modeling Laboratory, Technion, Israel Institute of Technology. The software offers a user-friendly environment that is understandable to the ordinary basic software user. When links not allowed by the OPM principles are about to be made, the software comes up with an announcement and prevent the creation of the link. It helps one to master the OPM rules and get the common sense of the possible relations between objects and processes. The software is freeware, with a possibility to buy a commercial version that creates an electronic database.

6 POWERTRAIN ATTRIBUTES MAPPING

To address the urgent need for a solution that will contribute to the organisational development in R&D activities, a system engineering approach has been applied in the research. The system engineering approach represents many advantages being used as a tool for mapping interactions between physical systems and highly personal expertise. One of the advantages is the graphical projection of the systems, therefore, making them more likely to be understood by non-proficient users. Together with the object-process language that supports diagrams, a user-friendly combination is created. Another important feature is the functionality of modelling languages that are built on a code, which allows further post processing. As the main drivers for moving the development forward are human centred design and simplicity for users, the Object-Process Methodology modelling language fulfils essential requirements in this application. OPM implies only 20 nodes with a comparison to UML that implies around 120 nodes (Dori, 2016). Because the system to be used for mapping powertrain attributes (NVH, P&D and emissions) requires a high level of simplicity, OPM has a positive assumption to suit well. It will allow the attribute leaders to easily present interconnections between the car system and its attributes to various stakeholder's groups within the organisation. At the same time, OPM allows the organisational members at the functional level to access the knowledge about systems, find their position in the development process and locate their activities within any complex system. A significant benefit is supposed to arrive for project leaders as well, being able to organise work structure by having access to the system map, which will show roles required in the ideal developing process as well as other subordinate processes affected by single actions.

6.1 Exhaust system

One example of the most logical approach and the one used for the purpose of this research starts with physical components that form the car itself. The major advantage is the possibility to build the system upon current car design, which is easily accessible in the organisational database as a 3D model with detail description of all parts. In this case, the basic processes done by the physical parts are easy to identify even without long experience within the automotive industry. Therefore, also understandable to a reader. The powertrain attributes mapping in this research has been done for an exhaust system, the part of a car that transports burn gases out of the car. For a complete understanding, figure 6.1 shows basic exhaust system layout.

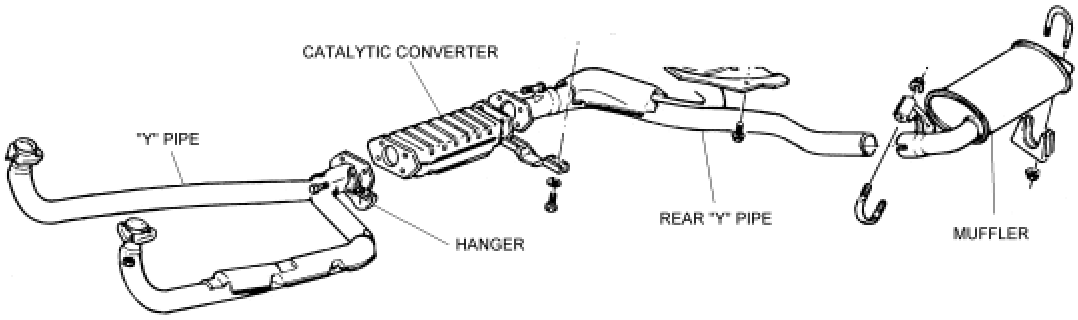


Figure 6.1 Basic exhaust system

As it can be seen in the picture the exhaust system components can be classified, and after short discussions with engineers, the complete function identified. Simultaneously, the figure 6.2 shows first OPM diagram, where the physical exhaust system is converted into OPM nodes, objects, and connected with a procedural link to the another OPM node representing a primary process, the gas exhausting. Single components in the small boxes are arranged in a big rectangular box, representing the parent relationship between the exhaust system and its components. The detail explanation is available in the object-process language, which can be found in appendix B.

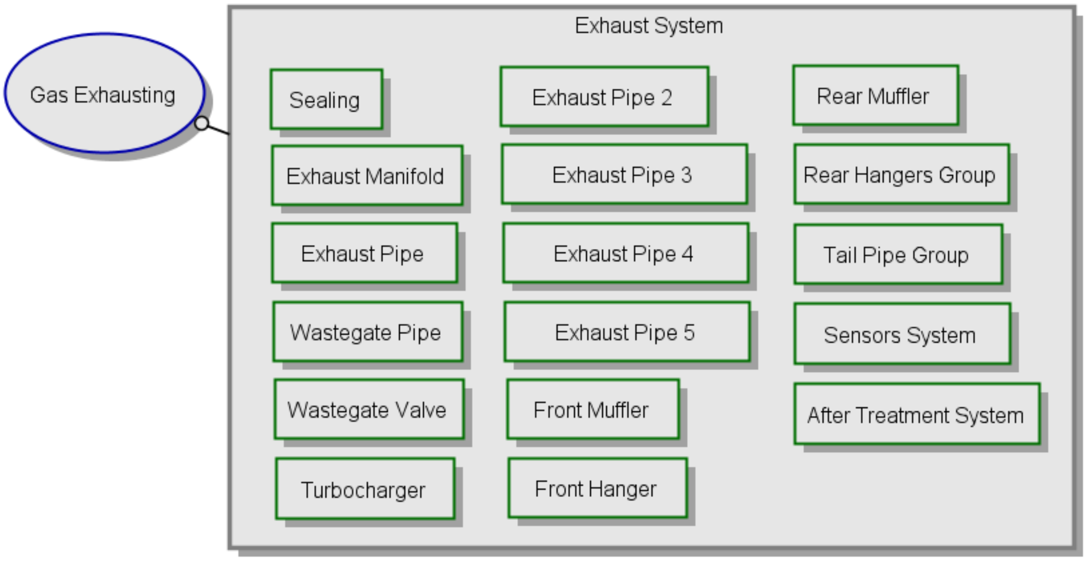


Figure 6.2 OPD Exhaust system

Zooming in the primary process of gas exhausting in figure 6.3, the diagram exhibit the mother process is broken down into four secondary processes, connected with a structural link expressing relationships between them. The top to bottom order reflects the order in which the processes occur, as it was derived from the exhaust system function. The primary process is accommodated in bigger shape than the secondary processes, highlighting the parent relationship. On the right-hand side, the primary function of the exhaust exhausting is displayed, changing the exhaust gas from toxic and noisy to treated and noise reduced. All of the secondary processes are employed to change the state of the exhaust gas. Additionally, in order to observe a holistic view, the relationship between the exhaust system and the primary process of gas exhausting and exhaust system is represented by the same procedural link as in figure 6.2.

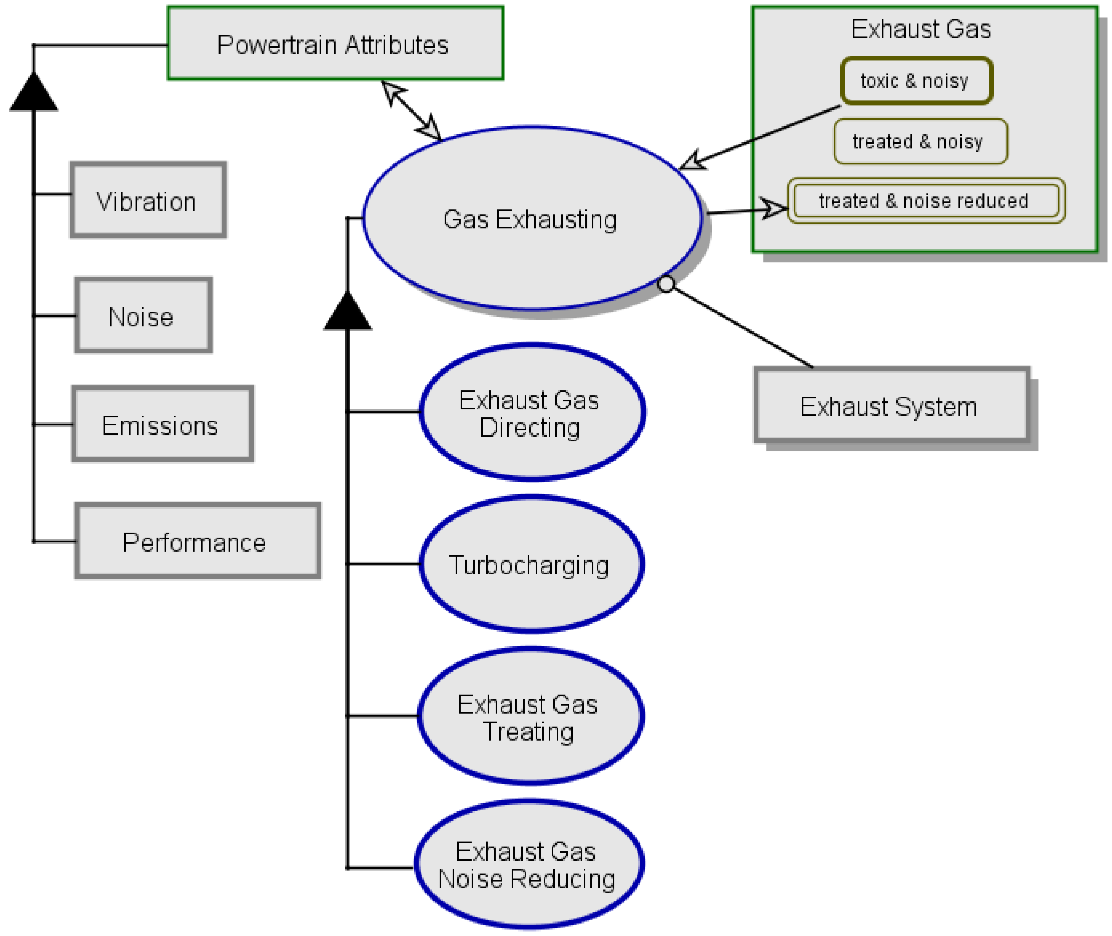


Figure 6.3 OPD Gas Exhausting

Each of the secondary processes can be zoomed into the more detail level. The level has no limitation as in the abstract world, an infinite number of levels can be designed. To reflect on the best practice how to describe a secondary process in more detail, the process of exhaust gas treating is presented in figure 6.4. When the process is zoomed in, it appears in a big ellipse that represents the secondary process, and smaller ellipses that represent a tertiary process. The tertiary processes either consume or yield objects that are organised on the left-hand side outside of the secondary process because the objects are not part of the process. As the theory of OPM states, the processes can only yield or consume process, and change its state. The physical components that are required for the processes to occur are allocated on the right-hand side. Some of the components are also characterised by certain parameters, as for example the after treatment system by its volume. The parameter of volume can be both smaller and bigger. Such specification is used mainly in other diagrams, where the behaviour of powertrain attributed is explained.

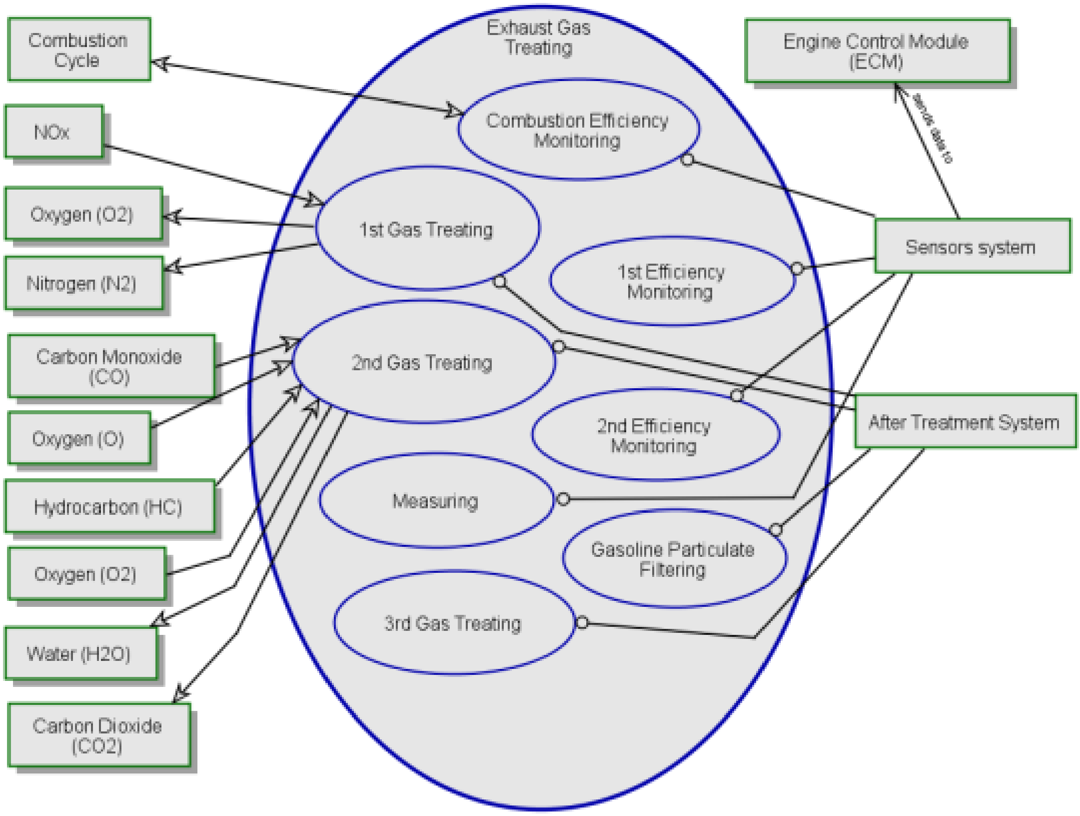


Figure 6.4 OPD Exhaust gas treating

6.2 Powertrain attributes

Mapping powertrains attributes is a complex process, as a trade-off should be always found not just between noise, vibrations, performance, driveability and emissions, but many others are typically involved. Therefore, a system how to map the attributes, and show the interactions between them with a connection to components parameters, has been developed as the part of the research project. In figure 6.3 the object of powertrain attributes can be seen in the green outlined rectangle. The object represents a top level for attributes, in this case, incorporating four powertrain attributes used for the pilot project. Each of the attributes is projected as objects in the grey outlined rectangle, the green colour instead of green discloses the fact that the particular object can be further in-zoomed. In figure 6.5 the noise attributed is displayed in the in-zoomed diagram. In this diagram, the booming noise behaviour within the gas exhaust system is mapped. The booming noise exists as an object in the universe, which is affected by two processes of increasing and decreasing that affects the noises. The processes require other objects (components) to be in a certain state to happen, it might be as simple as bigger valve open or closed, and volume bigger or smaller. It is a unique pattern developed for this purpose, allowing communication of attributes behaviour to the outside world. In the final stage, the behaviour is also represented by a sentence in natural English, i.e. “Booming noise reducing occurs if tail pipe length is shorter”. Such statements can be found in the object-process language, see appendix B.

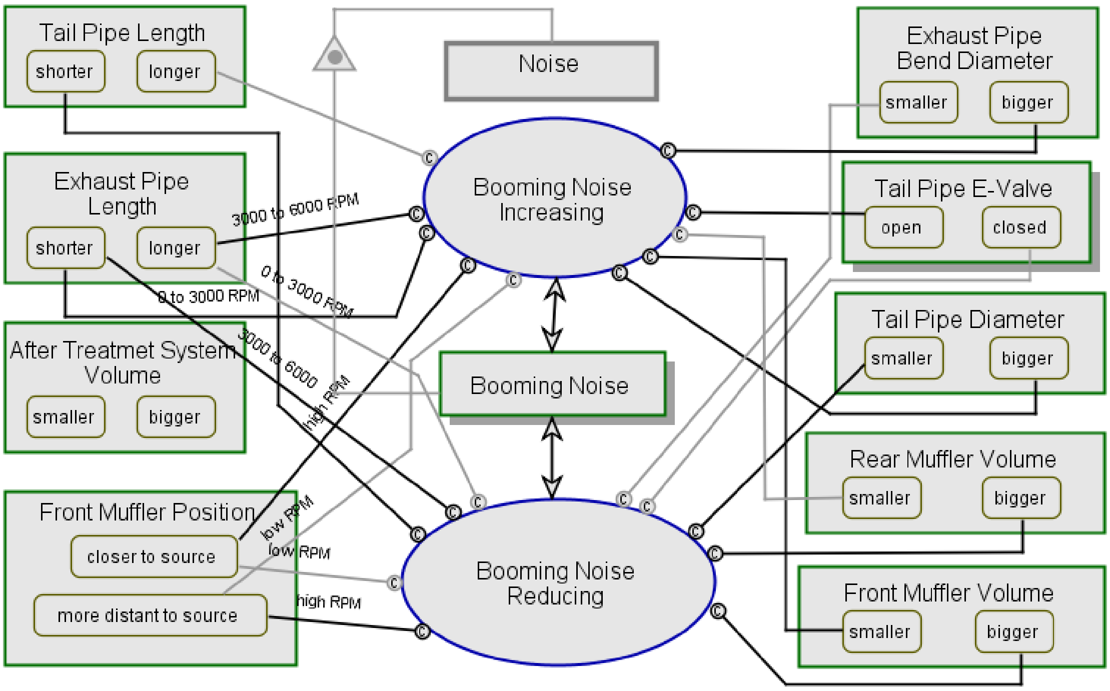


Figure 6.5 OPD Booming noise attribute

7 ANALYSIS

In chapter 3, a number of related works have been presented. In this chapter, an interaction between the frameworks presented and OPM application in the KM process is explained. The discussion does not describe details of content matching as that is a subject of further research. At the same time, an application of system engineering approach within knowledge management and balancing powertrain attributes is discussed.

7.1 OPM integration with presented frameworks

7.1.1 3-T framework context

The 3-T framework in figure 3.1 (Carlile, 2004) can benefit with OPM application in all three subprocesses in the knowledge sharing: transferring, translating and transforming.

At the bottom level of the framework, the process of transforming, utilisation of OPM offers seamless moving of the knowledge between senders and receivers as the systems engineering approach creates an interactive connection between agents (actors), as well as instruments, components systems behaviour, which represents the knowledge content. The dependencies between the knowledge sources are not represented by common lexicon, however, the functional connection represented by the behaviour of the system track the dependencies regardless of the lexicon used in the system. In other words, the OPM solution allows tracking knowledge sources based on the system functionality rather than using word based searching/tracking mechanism, i.e. look at booming noise behaviour in figure 6.5. Therefore, the extent to which the knowledge is considered as unknown in the 3-T framework is potentially reduced as the functionality reaches far over the common pool of words used in the database. In the real application it means that an individual trying to reach knowledge that is not familiar to him or her, he or she does not have to know the right words to look for rather just track the knowledge source according to the functionality to which the knowledge gap belongs.

In the following stage, usage of OPM is reducing the need for the process of translation. Since the 3-T framework works on the word lexicon base, translation takes place when novelty makes dependencies in the knowledge sources unclear (Carlile, 2004). Assuming that OPM works on the system behaviour and functional basis, knowledge represented by any novelty within systems is tracked based on the same principle as in the first process of knowledge transformation. In that sense, using OPM does not make any significant difference between the two processes as the knowledge is to be located on the same principle whenever is brought up by novelty or well-known wisdom. As a result, misinterpretation both in the process of transforming and translating are to be reduced as actors are able to locate the knowledge source based on its functional position in the system rather than based on the words which are familiar to them. In this sense, the language should not be considered as an important factor, therefore, also actors with limited knowledge of the language in which the knowledge content is stored can be able to track desired information.

Since OPM has the ability to plot all functional dependencies in an infinite database, the top process of transformation at the political boundary can find an opportunity but also a limitation while being handled in the OPM system. The opportunity is represented by the ability of OPM to show all the functional dependencies (see figure 6.4) between any knowledge source and its role in the system. One can assume that if various stakeholders observe all the dependencies, an agreement is to be reached and interests prioritised. However, the limitation threat is represented by exactly the same functionality as some stakeholders' interests might be eliminated by reprioritisation based on facts shown by the OPM database. Therefore, while OPM will increase the efficiency of the process, the final willingness of the actors stays a crucial factor in the process as Carlile (2004) points out.

Process	OPM Impact
Transferring	• Increasing efficiency • Reducing misinterpretation gap
Translating	• Eliminating process
Transforming	• Showing fully transparent dependencies to all stakeholders

Table 7.1 OPM Impact to 3-T framework

7.1.2 Knowledge query and request context

The PD knowledge framework shown in figure 3.3 (Zammit et al., 2016) will find many benefits when integrating with OPM solution in all its four process phases in the sustainable loop: querying, identifying, capturing and learning.

As OPM solution is built on a system functionality, the first phase of querying is somewhat similar to the process of transferring in the 3-T framework and works in an identical way when the actors locate the knowledge source based on dependencies in the knowledge content. In the same way, using the system behaviour structure increases the efficiency of the process as users (seekers) can easily connect through the behaviour structure to knowledge owners (experts). However, in this case, no communication channel is to be opened between the two actor groups as the experts' knowledge is already assumed to be stored in OPM database and shared in a fast way. Such time efficient knowledge sharing carries a threat of increasing misinterpretation as the knowledge providers are not directly involved.

In the second phase of identifying, the OPM provides knowledge seekers with fast access to complete knowledge database, therefore, significantly increases the efficiency of knowledge gap identifying. As an ideal OPM database carries owners of knowledge sources (not included in case study due to confidentiality concerns), the seekers are able to locate function owners who are with high probability possible addresses for the knowledge requests to fill the knowledge gaps. In most cases, the function owners of various parts of complex systems (i.e. figure 6.2) hold the right expertise. However, if not, those very likely know how to locate other individuals who pose with the knowledge being requested. The fact that OPM provides seekers with complete database based on system functionality also eliminated the necessary step in the framework step sanity checking if the knowledge gap has been already filled before.

Following a phase of capturing knowledge to fill the knowledge, gaps remain the same to some extent. The knowledge providers still either pose the knowledge themselves, locate other knowledge providers or acquire the knowledge from various sources such as books, the internet, manuals and more (Zammit et al., 2016). Utilisation of OPM in this process offers the knowledge providers smooth process of knowledge capturing by inserting the knowledge content into familiar OPM diagram database without significant interfering to other knowledge content. By doing so, the last phase of the framework is supported with OPM as knowledge request is addressed, knowledge gap filled and the new knowledge content accessible for all users in the system creating a sustainable process of knowledge sharing.

Phase	OPM Impact
Querying	• Reducing need for opening a communication channel between actors • Misinterpretation can increase as knowledge providers are not directly involved
Identifying	• Increasing efficiency of knowledge identifying • Tracking knowledge providers to address a knowledge gap • Functional dependencies eliminates need for manual check of knowledge existence
Capturing	• User-friendly creating of knowledge contained in a familiar database
Learning	• Knowledge stored in a sustainable way and available to particular seekers as well as other users

Table 7.2 OPM Impact to Query and Request framework

7.1.3 Knowledge recommendation context

In the same manner, as the latter two frameworks, even recommendation extended framework showed in figure 3.4 (Zhen et al., 2013) finds many beneficial aspects from OPM application. The function of the query portal is substituted system dependencies based on the functionality in the same way as querying phase and transferring process in the previous frameworks. However, in the case of this framework more technical discussion takes place. Using OPM users do not search knowledge by rising keywords based query requests for specific knowledge which is extracted from a knowledge repository, but have instant access to the knowledge repository – diagrams and process language transcripts. It means that when a specific knowledge is desirable, a user does not request knowledge content from a portal, rather accesses knowledge resource directly through a set of diagrams that lead to the specific function to which is the knowledge resource related. As the process handled with OPM solution provides users with a certain level of independence while working with knowledge database (repository), need for the query portal and most of the supply side in the framework would not be required. As an example, functions as category tagging, keyword tagging, description, basic management, query log and query portal itself would be eliminated. On the other hand, OPM application and the self-managing experience would not allow the knowledge system to collect data about knowledge being queried. But in an ideal case, that is not a game changer as the recommendation function is handled in a different way with OPM too.

Methods of vector-based and phrase-based recommendations enclose a sophisticated approach to match knowledge demand and supply and would work in an efficient way using OPL transcripts (see figure 5.2), OPM database is not primarily based on keywords principle. Therefore, the two methods can be neglected while handling knowledge management with OPM. As project teams in the developments teams of today are a mix of different roles and even similar roles in different teams owns various knowledge, recommending knowledge based on roles can end up being irrelevant. The same might be said about tasks and problem description – which can enclose high level of misinterpretation. Since users can access the knowledge database (diagrams) independently and surf through them base on system functionality and behaviour, the function of the demand side is carried by themselves. In an ideal case, a function owner observes all functional connections to other related functions and accesses the knowledge stored in the database himself or herself. In that sense, the actor uses the benefit of strong dependencies network to being provided with knowledge observed with diagrams or related functions, therefore, knowledge recommendations. A big limitation compares to the demand side function in the framework is that the intensity of recommendation of knowledge with which are the users provided is very depended on their intensity of surfing through the database (diagrams). If there is to be a proper function developed within the OPM solution, that one should use an algorithm which refines knowledge content to be recommended base on the dependencies in the system.

However, one can still argue how the knowledge from far distant functional areas can be recommended, i.e. between engine development units and production body shop.

Process	OPM Impact
Querying	• Users are provided with direct access to the knowledge database (repository) having self-managed querying experience • Most functions on the supply side to be eliminated
Recommending	• Users provided just with relevant knowledge recommendations • Most functions on the demand side to be eliminated • Limited knowledge transfer between far distant functional areas

Table 7.3 OPM Impact to extended Recommendation framework

7.2 Balancing powertrain attributes with knowledge management approach

The knowledge management approach proposed to balance powertrain attributes uses OPM solution as a basic database (repository). With the ability to represent the physical components, design processes, agents, instruments and relations between those in the diagrams and programming language, the methodology provide the model with a strong content. All processes within an organisation can be modelled in the same way as diagram 6.4 shows in the case exhaust gas treating process. Moreover, agents and instruments required for the process and subprocess are to be included (excluded for confidentiality reasons). Once the basic diagram is finished, more sophisticated diagramming can take place as figure 6.5 shows. In this case, the objects do not serve just as inputs or outputs for a process, but the processes change states of the objects. This diagram shows the change just in a simple way using words such as "smaller" and "bigger", however, in the real application algorithms, sophisticated formulas and various phrases explaining system behaviour are used. The main advantage of the system engineering approach is an ability to map systems starting with the basic physical components (see figures 6.1 and 6.2), being enriched with processes, agents, instruments and their interrelations. Once most areas of the VPD such as Powertrain Attributes, Functional Disposition, Activity Planning and Sign-off process are modelled (set of areas described in chapter 4), the interconnections between those show dependencies of the system behaviour in various contexts. Such approach allows the knowledge sources to be instantly connected and located based on system functionality.

Assuming that most of the system behaviour is captured in the database and interconnected based on the functionality of the whole as well as single components, the Powertrain Attributes leaders will be able to balance attributes based on the knowledge extracted from the database. An easy example can be found in the case study conducted in this research project. If a Powertrain Attribute leader faces a problem of excessive booming noise in the car passenger compartment, there is a need to reduce the level of the noise. Instead of going through a complex process explain in chapter 4, the attribute leader will simply open the object of noise in the OPM database and subsequently get to object to booming noise and process of booming noise reducing (see figure 6.5. When opening such diagram, the attribute leader can immediately see how should parameters of each component connected to the process of booming noise reducing changed. Important to point out that such activity can happen without querying or requesting the knowledge source but surfing the knowledge database in an incredibly intuitive way based on functionality instead. Moreover, as in the fully operating database roles of the agents (function owners) are enclosed, the attribute leader is able to notify other function owners about the intention of changing his or her function based on the knowledge context available in the database. This inevitable step helps to notify other actors about the change as well as adding an opportunity to collaborate and add new knowledge sources later in time based on accumulated experience from ongoing activity.

Table 7.4 shows possible scenarios how would be knowledge accessed in the process of balancing powertrain attributes using frameworks presented in chapter 3.

Process	Process of accessing knowledge
3-T Framework **(Carlile, 2004)**	Locating knowledge content based on word pool in common lexicon in the process of transferring.
Knowledge query and request **(Zammit et al., 2016)**	Locating knowledge content with a query based keywords followed by searching in a database.
Knowledge recommendation extended framework **(Zhen et al., 2013)**	Querying knowledge source based on categories, keywords, or description in a database.
Object-Process Methodology (OPM) **(Dori, 2002)**	Locating knowledge sources based on functionality interconnected to a system and its single components. Once a knowledge source located in a database, the knowledge content available in a visual form (diagrams) and word based transcript (process language).

Table 7.4 Comparison of accessing knowledge in presented frameworks and OPM

7.3 Functionally connected knowledge sources

One of the strong benefits of the OPM is the functionally connected knowledge content. In the previous research at Volvo Car Corporation, a structure of functional connection is suggested. Ahlstedt (2015) proposed a framework which is divided into four levels starting with the top level of the complete vehicle, followed with complete powertrain, single powertrain functions, sub-systems and ending with hardware components at the bottom level. Such structure allows the knowledge sources to be intuitively located from the top down perspective starting with the complete vehicle.

Törmänen et al. (2017) propose a structure for capturing the knowledge content across multiple domains with in a system architecture. The captured knowledge in the OPM architecture includes answers for questions: "why a system is developed, what process the system is supposed to solve, how these functions are accomplished and who knows the owner of a system" (Törmänen et al., 2017, p. 11). If the system knowledge is described by all these parameters, it's location in the broader context is rigid and can be intuitively located as "knowledge from the different contexts will be aligned around different physical processes" (Törmänen et al., 2017, p. 15). On the top of that, using the structure proposed by the research group also allows to facilitate communication and share understanding amongst development teams to support knowledge transfer.

7.4 Limitations for OPM implementation

Various challenges come up with the OPM application. According to the case study and the analysis in this work, the OPM can be seen to be a way forward in digitalising knowledge management. However, same as the system engineering approach will answer many challenged, some will still be out there to be solved. This work develops an argument for the middle level of translating in the 3-T framework to be eliminated. On the negative argument side, there is a concern that misinterpretation gaps will not be fully eliminated but just reduce to certain extend as shown in the figure 7.1. As individuals in the organisation have got different professional and social backgrounds, the variety of interpretation is somewhat big. The OPM solution has a big potential to solve many problems with reducing the misinterpretation gaps between actors, but not solve the misunderstanding completely.

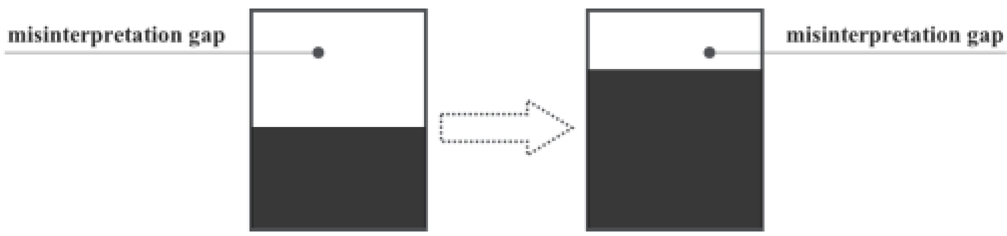


Figure 7.1 Misinterpretation gap elimination

The third level of the 3-T framework will face challenges as well, as it requires willingness of actors to share with each other. Observing full transparency in the system will help to develop actors' understanding to the context as stated in the table 7.1, however, it would be very naive to expect that all the organisational members in any organisation will use the understanding in a proper way. Moreover, interests of stakeholders and function owners in research and development organisations often heavily overlaps. Sometimes, such overlaps are desired to be found in order to improve efficiency of processes and product development. On the other hand, on many occasions now one know how much political tension will be brought up with observing overlaps which has not been well understood before. Therefore, the argument says that full understanding of the context at the political boundary can have a negative impact on the operations.

Once a technical solution of an OPM system is design and developed, the implementation in the daily operations will take place. Even though the OPM is an easy system engineering architecture compare to others, the implementation phase will require training of diagramming and OPM language skills to all actors across the organisation who are intended to work in the database in the future. Some actors might not be able to learn such methodology in a given period, or be very defensive towards the method at all. There reasons might be various, starting with limited skills to visualise stretching up to limited skills to articulate ideas. There is a threat in the system acceptance from the actors' side, which is very difficult to predict at the moment. Such threat is a subject for another scientific study.

Assuming that system and trainings are developed, a transition period has to take place. The transition period will not most likely happen overnight, and a critical element is to keep actors engaged at the time when the database is not full of content. The engagement in the early phase possess an incredible threat for the transition period, as the system content is mean to be the main attractor for users to keep engaging with the system and turn it in their benefits. However, it can be assumed that the content in the database will raise with the number of users being involved. Therefore, going through the transition period will eliminate the threat of the content-related engagement.

8 CONCLUSION

The business environment of the past decades has been rapidly changing its landscape moving from paper back administration to digital based administration. Globalisation and internationalisation are continuously increasing the number of cross-location collaborative activities internally within an organisation, but also externally in joint ventures and other business to business arrangements. Many organisations have been transferring line operations in product development to project based work streams, which require more intense administration as more stakeholders from various functions and locations are involved. Therefore, Project Management is getting more attention as a management practice and management science too. Consequently, the field of Knowledge Management has been becoming one of the basic pillars of general knowledge management practice (Management, 2012, Boddy, 2002, Kerzner, 2013, Project Management Institute, 2013). Scholars come up with new terms such as New Product Development (NPD) and Knowledge-based Development (KBD), which has been inevitably becoming parts of project based operations in engineering establishments worldwide. This research project has been devoted to studying the application of a system engineering approach, Object- Process Methodology (OPM), in balancing powertrain attributes in research and development operations at Volvo Car Corporation in Gothenburg, Sweden. The proposed approach indicates that accumulated knowledge can be used for a very specific activity if captured, stored and shared in an intuitive way. In that sense, the research project is extending the boundaries in knowledge management to the operational level of many other activities, rather than serving just as a knowledge pool available while problem-solving particular issues.

The researched project has been initiated by a group of experts in Powertrain Department in Volvo Car Corporation. After initial discussions with various stakeholders, a review of related works has been done. Three theoretical frameworks enclosing possible setup of managing knowledge were chosen to compare the application of OPM. No studies similar to planned research goal has been found. In the next stage, data for the case study were collected. Secondary data representing hardware components and its arrangement in a physical system, and primary data represented by deep technical knowledge acquired by interviewing Volvo Car Corporation engineers. Case study consisting of diagrams and their process language transcripts was created. The result of the study shows successful application of OPM in storing knowledge in system engineering architecture. The diagrams can store knowledge such as system behaviour based on system functionality which is defined by objects (single components), processes and relationships between them (see figure 6.3). By designing the system hardware infrastructure, itself, another opportunity how to store the knowledge about the system itself is born (before normally just drawings, 3D models and text notes). The powerful combination of having stored hardware infrastructure layout and system behaviour knowledge in one intuitive platform such as OPM provides users with the luxury of having instant and fast access to desirable knowledge while surfing through diagrams. No keywords are used to locate the right functions. In the case of balancing powertrain attributes, the attribute leaders would be able to locate their attributed in the physical system and extract knowledge from a relationship between object (component) parameters and its relationship to any process directly connected to the object. The knowledge extracted help them to make a balanced decision about components specifications and see relationships to other concerned components.

As the result of the study shows, the highly technical knowledge such as booming noise behaviour or back pressure (Appendix B) in an exhaust system of a vehicle can be represented in a cross-functional context using OPM solution. The knowledge is stored by modelling hardware system and capturing all process that influences each parameter. Assuming OPM is implemented within many functional units, i.e. Powertrain Attributes, Functional Disposition and Sing-off process, all the objects and processes (knowledge content) are interconnected by relationships between them. All functional units using the same OPM platform are able to see their dependencies to all other components and processes in the system. Therefore, the solution provides users with the ability to share knowledge content in a cross-functional environment.

With balancing the powertrain attributes using knowledge captured, stored and shared in OPM platform, all the major resources of project management, time, cost and performance (Kerzner, 2013) will be better utilized. Having instant access to the knowledge sources will save to attribute leaders' weeks of searching the right knowledge owners. As a result of that, the performance of the project teams will increase as they will work in a more agile and flexible way. On the top of that, car developing projects will become less expensive as many targets exceeding attributes are discovered when the first prototypes of cars are built. With the right balancing of the attributes in the early design phase, hypothetically less will be required to build and less engineering changes to be done.

Due to the confidentiality reasons only well-known technical knowledge has been available for use in the case study. Some can bring arguments that the fact that the set of knowledge being represented in the system engineering architecture in chapter 4 is not highly technical knowledge rather just general knowledge of many engineers in the VPD. Such fact can represent limitations for the case study as the conclusion might be slightly different while using more complex and highly confidential knowledge contact in the case study. Another limitation is the fact that rather a small part of the non-complex physical system (exhaust system) has been presented in the case study. Such does not include electronic systems and software functions, meaning that the processes performed by single components in the system are somehow similar. The result of the study might differ if more software functions are involved as the interdependencies might not be seen directly in the diagrams.

The successful implementation of OPM solution is not just about storing and accessing knowledge individually in the system, however, integration with other organisational systems is a must. Therefore, there is an urgent need for future research in the field of OPM integration in engineering soft wares such as Teamcenter. Having OPM working with engineering software of same nature will make modelling much easier as the whole hardware (component) infrastructure and some parameters can be imported into diagrams. Furthermore, having OPM integrated with various mathematical software will allow smart post-processing of the diagrams and fully utilise the knowledge and the interdependencies in the database.

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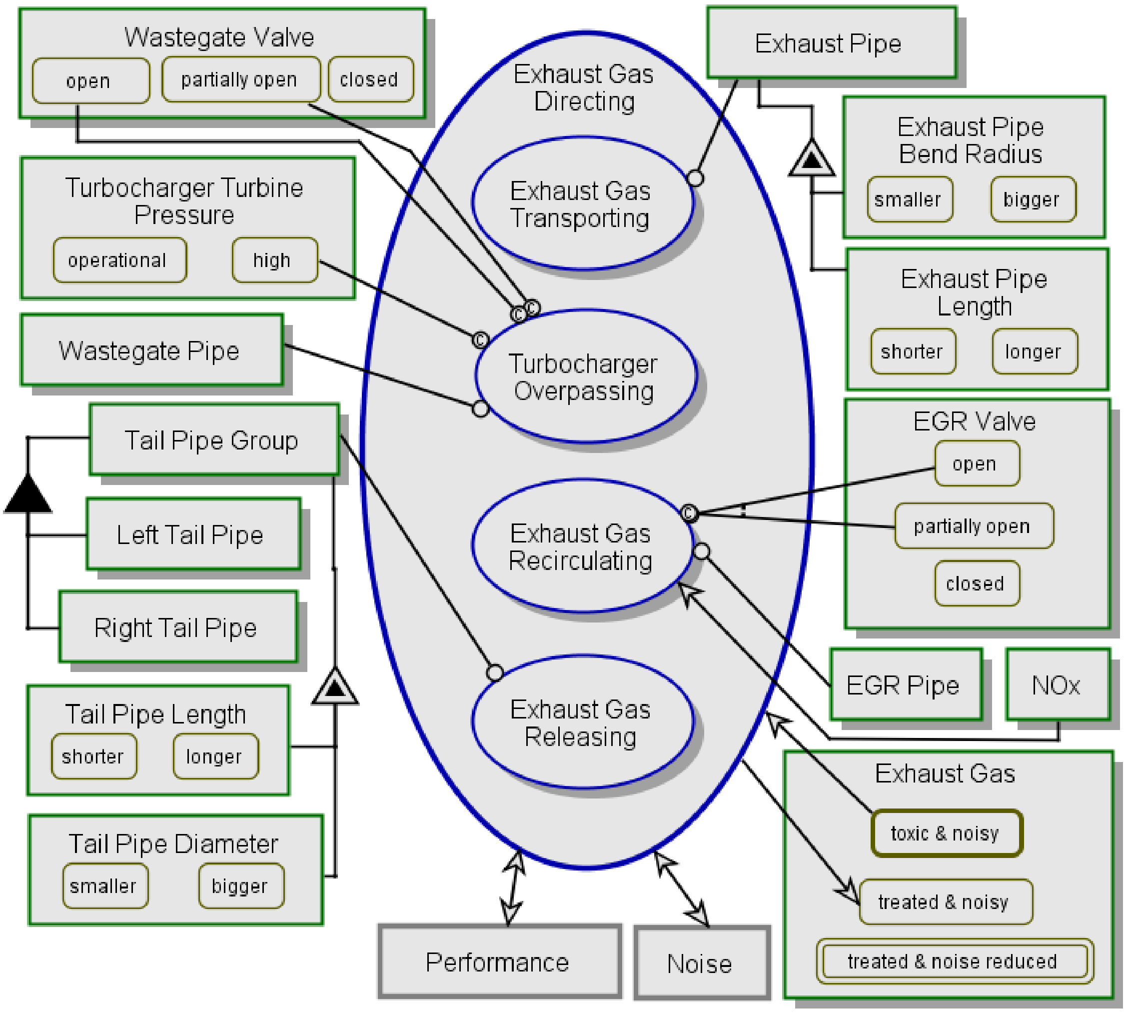
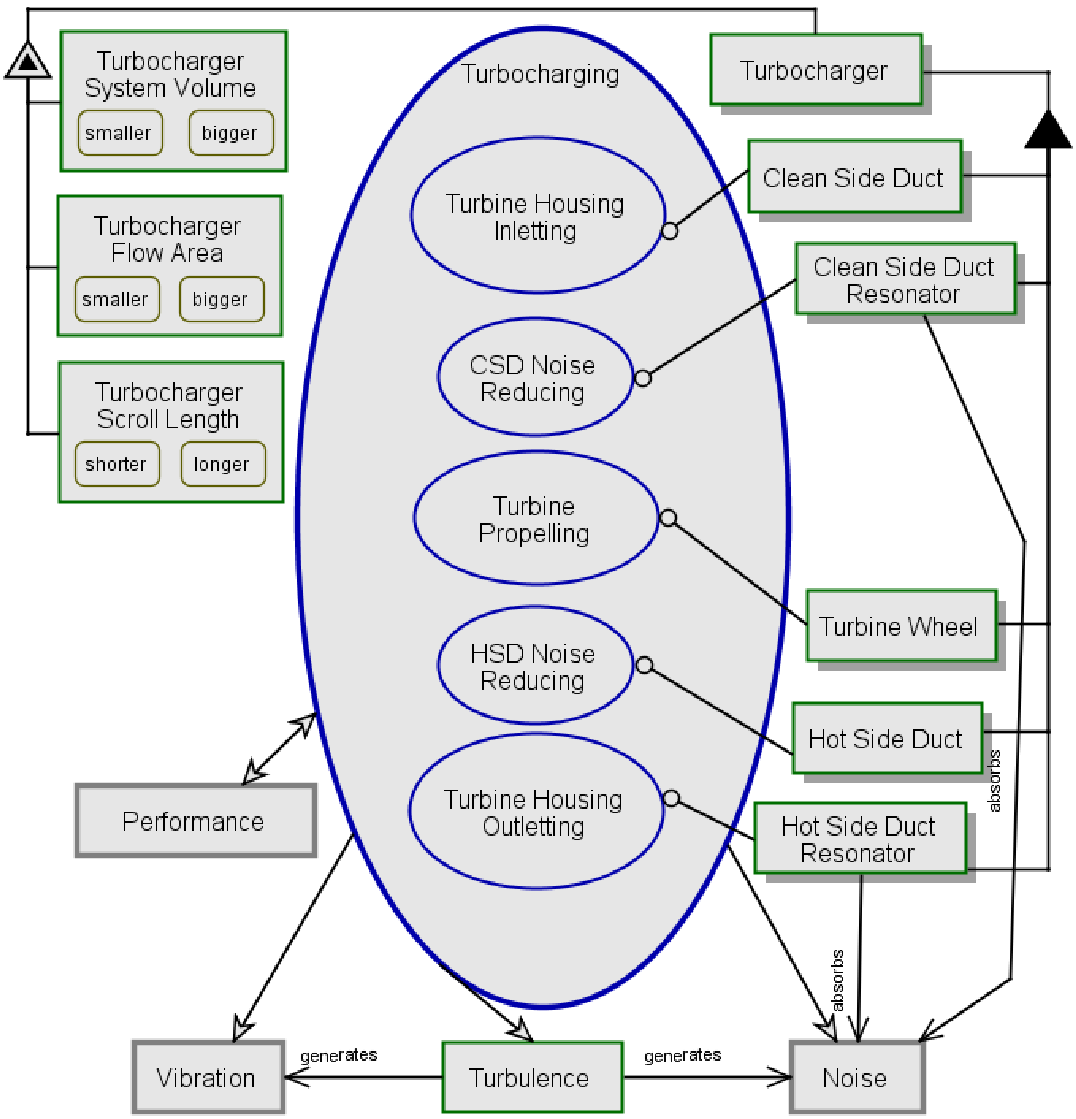
APPENDIX A

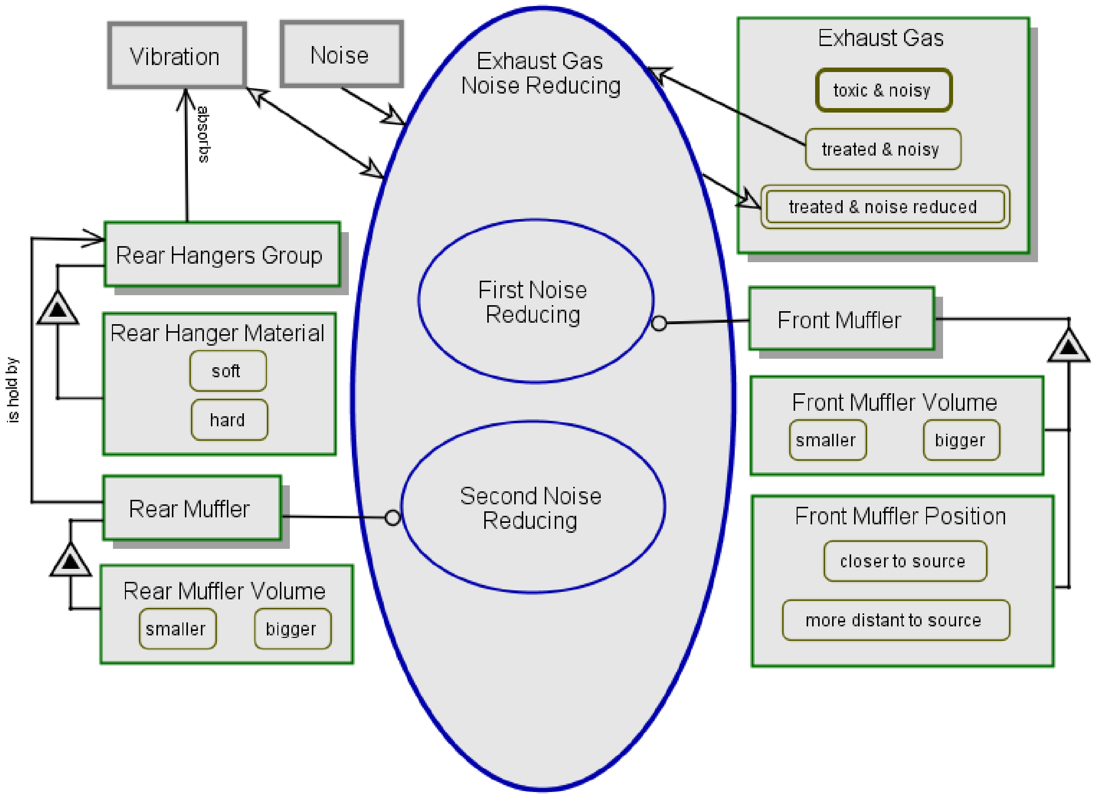
Exhaust Gas Directing



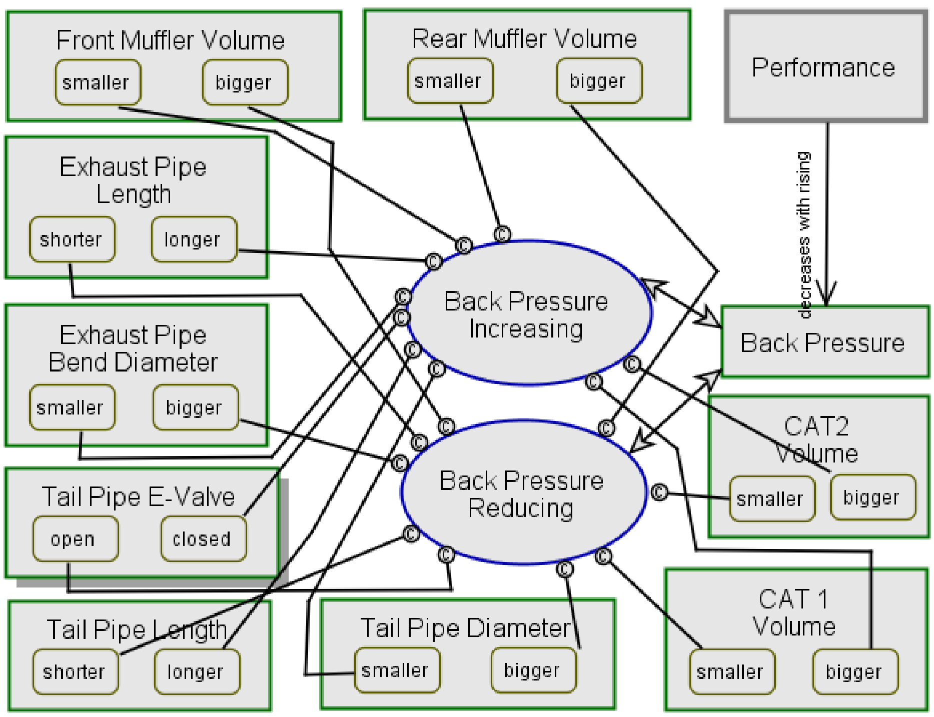
Turbocharging



Exhaust Gas Noise Reducing



Back Pressure Increasing and Reducing



APPENDIX B

Gas Exhausting

Powertrain Attributes consists of Noise, Performance, Emissions, and Vibration.
Exhaust Gas is physical.
Exhaust Gas can be toxic & noisy, treated & noise reduced, or treated & noisy.
toxic & noisy is initial.
treated & noise reduced is final.
Exhaust System is physical.
Gas Exhausting is physical.
Gas Exhausting consists of Exhaust Gas Directing, Exhaust Gas Treating, Exhaust Gas Noise Reducing, and Turbocharging.
Gas Exhausting requires Exhaust System.
Gas Exhausting affects Powertrain Attributes.
Gas Exhausting changes Exhaust Gas from toxic & noisy to treated & noise reduced.

Exhaust Gas Treating

NOx is physical.
Oxygen (O2) is physical.
Nitrogen (N2) is physical.
Carbon Monoxide (CO) is physical.
Oxygen (O) is physical.
Carbon Dioxide (CO2) is physical.
Hydrocarbon (HC) is physical.
Oxygen (O2) is physical.
Water (H2O) is physical.
Engine Control Module (ECM) is physical.
Sensors system sends data to Engine Control Module (ECM).
Exhaust Gas Treating consists of Combustion Efficiency Monitoring, 1st Gas Treating, 1st Efficiency Monitoring, 2nd Efficiency Monitoring, 2nd Gas Treating, Gasoline Particulate Filtering, Measuring, and 3rd Gas Treating.
Exhaust Gas Treating zooms into Combustion Efficiency Monitoring, 1st Gas Treating, 1st Efficiency Monitoring, 2nd Gas Treating, 2nd Efficiency Monitoring, Measuring, Gasoline Particulate Filtering, and 3rd Gas Treating.
Combustion Efficiency Monitoring requires Sensors system.
Combustion Efficiency Monitoring affects Combustion Cycle.
1st Gas Treating requires After Treatment System.
1st Gas Treating consumes NOx.
1st Gas Treating yields Nitrogen (N2) and Oxygen (O2).
1st Efficiency Monitoring requires Sensors system.
2nd Gas Treating requires After Treatment System.
2nd Gas Treating consumes Oxygen (O2), Hydrocarbon (HC), Oxygen (O), and Carbon Monoxide (CO).
2nd Gas Treating yields Carbon Dioxide (CO2) and Water (H2O).
2nd Efficiency Monitoring requires Sensors system.
Measuring requires Sensors system.
Gasoline Particulate Filtering requires After Treatment System.
3rd Gas Treating requires After Treatment System.

Exhaust System

Exhaust System is physical.
Exhaust System consists of Sealing, Exhaust Manifold, Exhaust Pipe, Wastegate Pipe, Wastegate Valve, Turbocharger, Exhaust Pipe 2, Sensors System, Exhaust Pipe 3, After Treatment System, Exhaust Pipe 4, Front Muffler, Exhaust Pipe 5, Front Hanger, Rear Muffler, Rear Hangers Group, and Tail Pipe Group.
Exhaust System zooms into Tail Pipe Group, Rear Hangers Group, Rear Muffler, Front Hanger, Exhaust Pipe 5, Front Muffler, Exhaust Pipe 4, After Treatment System, Exhaust Pipe 3, Sensors System, Exhaust Pipe 2, Turbocharger, Wastegate Valve, Wastegate Pipe, Exhaust Pipe, Exhaust Manifold, and Sealing.

Tail Pipe Group is physical.
Rear Hangers Group is physical.
Rear Muffler is physical.
Front Hanger is physical.
Exhaust Pipe 5 is physical.
Front Muffler is physical.
Exhaust Pipe 4 is physical.
After Treatment System is physical.
Exhaust Pipe 3 is physical.
Sensors System is physical.
Exhaust Pipe 2 is physical.
Turbocharger is physical.
Wastegate Valve is physical.
Wastegate Pipe is physical.
Exhaust Pipe is physical.
Exhaust Manifold is physical.
Sealing is physical.

Gas Exhausting is physical.
Gas Exhausting requires Exhaust System.

Noise Attribute

Tail Pipe E-Valve is physical.
Tail Pipe E-Valve can be open or closed.
Tail Pipe Length can be shorter or longer.
Tail Pipe Diameter can be smaller or bigger.
Exhaust Pipe Bend Radius can be smaller or bigger.
Exhaust Pipe Length can be shorter or longer.
CAT 1 Volume can be smaller or bigger.
CAT2 Volume can be smaller or bigger.
Rear Muffler Volume can be smaller or bigger.
Front Muffler Volume can be smaller or bigger.
Front Muffler Position can be closer to source or more distant to source.
Exhaust Pipe Bend Diameter can be smaller or bigger.
Flow Noise is physical.
Flow Noise is instance of a Noise.
Booming Noise is physical.
Booming Noise is instance of a Noise.

Flow Noise Increasing occurs if Rear Muffler Volume is smaller, CAT 1 Volume is smaller, CAT2 Volume is smaller, Front Muffler Position is closer to source, Exhaust Pipe Length is longer, Exhaust Pipe Bend Radius is smaller, Exhaust Pipe Bend Diameter is smaller, Tail Pipe Diameter is smaller, and Tail Pipe E-Valve is closed.
Following path high RPM high RPM, Flow Noise Increasing occurs if Front Muffler Volume is smaller.
Flow Noise Increasing affects Flow Noise.
Flow Noise Reducing occurs if CAT 1 Volume is bigger, CAT2 Volume is bigger, Rear Muffler Volume is bigger, Front Muffler Volume is bigger, Exhaust Pipe Length is shorter, Exhaust Pipe Bend Radius is bigger, Exhaust Pipe Bend Diameter is bigger, Tail Pipe Diameter is bigger, and Tail Pipe E-Valve is open.
Following path high RPM high RPM, Flow Noise Reducing occurs if Front Muffler Position is more distant to source.
Flow Noise Reducing affects Flow Noise.
Booming Noise Increasing occurs if Tail Pipe Length is longer, Rear Muffler Volume is smaller, Front Muffler Volume is smaller, Exhaust Pipe Bend Diameter is bigger, Tail Pipe Diameter is bigger, and Tail Pipe E-Valve is open.
Following path 0 to 3000 RPM 0 to 3000 RPM, Booming Noise Increasing occurs if Exhaust Pipe Length is shorter.
Following path 3000 to 6000 RPM 3000 to 6000 RPM, Booming Noise Increasing occurs if Exhaust Pipe Length is longer.
Following path high RPM high RPM, Booming Noise Increasing occurs if Front Muffler Position is closer to source.
Following path low RPM low RPM, Booming Noise Increasing occurs if Front Muffler Position is more distant to source.
Booming Noise Increasing affects Booming Noise.
Booming Noise Reducing occurs if Tail Pipe Length is shorter, Rear Muffler Volume is bigger, Front Muffler Volume is bigger, Exhaust Pipe Bend Diameter is smaller, Tail Pipe Diameter is smaller, and Tail Pipe E-Valve is closed.
Following path 0 to 3000 RPM 0 to 3000 RPM, Booming Noise Reducing occurs if Exhaust Pipe Length is longer.
Following path 3000 to 6000 RPM 3000 to 6000 RPM, Booming Noise Reducing occurs if Exhaust Pipe Length is shorter.
Following path high RPM high RPM, Booming Noise Reducing occurs if Front Muffler Position is more distant to source.
Following path low RPM low RPM, Booming Noise Reducing occurs if Front Muffler Position is closer to source.
Booming Noise Reducing affects Booming Noise.

Exhaust Gas Directing

Exhaust Pipe is physical.
Exhaust Pipe exhibits Exhaust Pipe Bend Radius and Exhaust Pipe Length.
    Exhaust Pipe Bend Radius can be smaller or bigger.
    Exhaust Pipe Length can be shorter or longer.
Wastegate Pipe is physical.
Wastegate Valve is physical.
Wastegate Valve can be open, partially open, or closed.
EGR Pipe is physical.
Tail Pipe Group is physical.

Tail Pipe Group exhibits Tail Pipe Length and Tail Pipe Diameter.

Tail Pipe Length can be shorter or longer.

Tail Pipe Diameter can be smaller or bigger.

Tail Pipe Group consists of Left Tail Pipe and Right Tail Pipe.

Left Tail Pipe is physical.

Right Tail Pipe is physical.

Turbocharger Turbine Pressure can be operational or high.

EGR Valve is physical.

EGR Valve can be open, partially open, or closed.

NOx is physical.

Exhaust Gas is physical.

Exhaust Gas can be toxic & noisy, treated & noisy, or treated & noise reduced.

toxic & noisy is initial.

treated & noise reduced is final.

Exhaust Gas Directing consists of Exhaust Gas Transporting, Turbocharger Overpassing, Exhaust Gas Recirculating, and Exhaust Gas Releasing.

Exhaust Gas Directing affects Noise and Performance.

Exhaust Gas Directing changes Exhaust Gas from toxic & noisy to treated & noisy.

Exhaust Gas Directing zooms into Exhaust Gas Transporting, Turbocharger Overpassing, Exhaust Gas Recirculating, and Exhaust Gas Releasing.

Exhaust Gas Transporting is physical.

Exhaust Gas Transporting requires Exhaust Pipe.

Turbocharger Overpassing is physical.

Turbocharger Overpassing occurs if Wastegate Valve is partially open, Wastegate Valve is open, and Turbocharger Turbine Pressure is high.

Turbocharger Overpassing requires Wastegate Pipe.

Exhaust Gas Recirculating is physical.

Exhaust Gas Recirculating occurs if either EGR Valve is open or EGR Valve is partially open.

Exhaust Gas Recirculating requires EGR Pipe.

Exhaust Gas Recirculating consumes NOx.

Exhaust Gas Releasing is physical.

Exhaust Gas Releasing requires Tail Pipe Group.

<u>Turbocharging</u>

Turbocharger is physical.

Turbocharger exhibits Turbocharger System Volume, Turbocharger Flow Area, and Turbocharger Scroll Length.

Turbocharger System Volume can be smaller or bigger.

Turbocharger Flow Area can be smaller or bigger.

Turbocharger Scroll Length can be shorter or longer.

Turbocharger consists of Clean Side Duct, Clean Side Duct Resonator, Hot Side Duct, Hot Side Duct Resonator, and Turbine Wheel.

Clean Side Duct is physical.

Clean Side Duct Resonator is physical.

Clean Side Duct Resonator absorbs Noise.

Hot Side Duct is physical.

Hot Side Duct Resonator is physical.

Hot Side Duct Resonator absorbs Noise.

Turbine Wheel is physical.
Turbulence generates Noise.
Turbulence generates Vibration.
Turbocharging consists of Turbine Housing Inletting, Turbine Propelling, Turbine Housing Outletting, CSD Noise Reducing, and HSD Noise Reducing.
Turbocharging affects Performance.
Turbocharging yields Turbulence, Noise, and Vibration.
Turbocharging zooms into Turbine Housing Inletting, CSD Noise Reducing, Turbine Propelling, HSD Noise Reducing, and Turbine Housing Outletting.
Turbine Housing Inletting requires Clean Side Duct.
CSD Noise Reducing requires Clean Side Duct Resonator.
Turbine Propelling requires Turbine Wheel.
HSD Noise Reducing requires Hot Side Duct.
Turbine Housing Outletting requires Hot Side Duct Resonator.

Exhaust Gas Noise Reducing

Booming Noise is instance of a Noise.
Booming Noise Increasing occurs if Tail Pipe Length is longer, Rear Muffler Volume is smaller, Front Muffler Volume is smaller, Exhaust Pipe Bend Diameter is bigger, Tail Pipe Diameter is bigger, and Tail Pipe E-Valve is open.
Following path 0 to 3000 RPM 0 to 3000 RPM, Booming Noise Increasing occurs if Exhaust Pipe Length is shorter.
Following path 3000 to 6000 RPM 3000 to 6000 RPM, Booming Noise Increasing occurs if Exhaust Pipe Length is longer.
Following path high RPM high RPM, Booming Noise Increasing occurs if Front Muffler Position is closer to source.
Following path low RPM low RPM, Booming Noise Increasing occurs if Front Muffler Position is more distant to source.
Booming Noise Increasing affects Booming Noise.
Booming Noise Reducing occurs if Tail Pipe Length is shorter, Rear Muffler Volume is bigger, Front Muffler Volume is bigger, Exhaust Pipe Bend Diameter is smaller, Tail Pipe Diameter is smaller, and Tail Pipe E-Valve is closed.
Following path 0 to 3000 RPM 0 to 3000 RPM, Booming Noise Reducing occurs if Exhaust Pipe Length is longer.
Following path 3000 to 6000 3000 to 6000, Booming Noise Reducing occurs if Exhaust Pipe Length is shorter.
Following path high RPM high RPM, Booming Noise Reducing occurs if Front Muffler Position is more distant to source.
Following path low RPM low RPM, Booming Noise Reducing occurs if Front Muffler Position is closer to source.
Booming Noise Reducing affects Booming Noise.

OPL Performance Attribute
Turbocharger System Volume can be smaller or bigger.
Turbocharger Flow Area can be smaller or bigger.
Turbocharger Scroll Length can be shorter or larger.
Turbocharger Turbine Pressure can be operational or high.
Wastegate Valve is physical.
Wastegate Valve can be open, partially open, or closed.
Tail Pipe E-Valve is physical.
Tail Pipe E-Valve can be open or closed.
Tail Pipe Length can be shorter or longer.
Tail Pipe Diameter can be smaller or bigger.
Exhaust Pipe Length can be shorter or longer.
EGR Valve is physical.
EGR Valve can be open, partially open, or closed.
CAT 1 Volume can be smaller or bigger.
CAT2 Volume can be smaller or bigger.
Rear Muffler Volume can be smaller or bigger.
Front Muffler Volume can be smaller or bigger.
Exhaust Pipe Bend Diameter can be smaller or bigger.
Performance decreases with rising Back Pressure.
Back Pressure Increasing occurs if Tail Pipe Diameter is smaller, Tail Pipe Length is longer, Tail Pipe E-Valve is closed, Exhaust Pipe Bend Diameter is smaller, Rear Muffler Volume is smaller, Front Muffler Volume is smaller, CAT 1 Volume is bigger, CAT2 Volume is bigger, and Exhaust Pipe Length is longer.
Back Pressure Increasing affects Back Pressure.
Back Pressure Reducing occurs if Rear Muffler Volume is bigger, Front Muffler Volume is bigger, CAT 1 Volume is smaller, CAT2 Volume is smaller, Exhaust Pipe Length is shorter, Exhaust Pipe Bend Diameter is bigger, Tail Pipe E-Valve is open, Tail Pipe Length is shorter, and Tail Pipe Diameter is bigger.
Back Pressure Reducing affects Back Pressure.

APPENDIX C

In this appendix, detail analysis of word count for every chapter is provided.

Chapter	Word Count
1. Introduction	1,051
2. Method	2,969
3. Related Works	2,823
4. Organisational Challenge	3,173
5. Object-Process Methodology	1,581
6. Powertrain Attributes Mapping	1,145
7. Analysis	3,211
8. Conclusion	1,048
TOTAL	**17,001**

According to Northumbria University regulations the length of a master dissertation/thesis should be 15,000 words or an absolute maximum of 20,000 words.

APPENDIX D

Research project for a Master Thesis in
Project Management.

"Balancing Powertrain Attributes Using Object-Process Methodology".

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