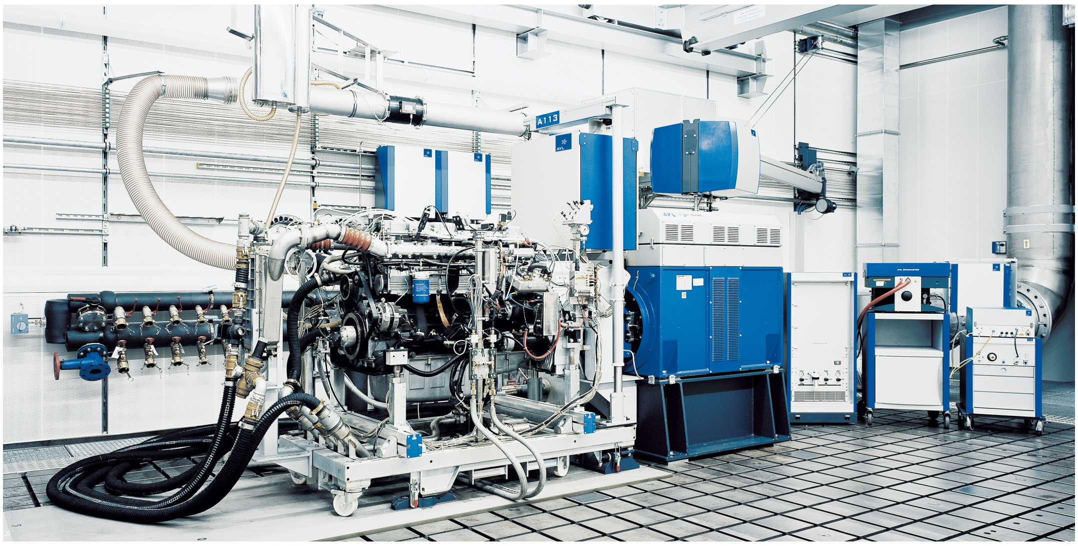

Review of maintenance structure to increase test field output

Master's Thesis in Systems, Control and Mechatronics

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Abstract

During the development of new vehicle models, a variety of different tests are performed. The tests verify that each vehicle satisfies emission legislation, durability as well as driving characteristic and performance. To perform these tests, advanced test cells and equipment are required. However, one big obstacle with test cells of this kind, is to achieve and maintain a high level of efficiency and utilization. One factor of decreased utilization is the unplanned stops of a test cell due to maintenance of the equipment and sensors.

To prevent the cells from these unplanned stops, an analysis of the cells is necessary. With an analysis can a greater understanding of the reasons behind the malfunctions be obtained. With a understanding of the reasons behind the stops, a solution can be found, a solution incorporated with the automation system.

Two companies, one light duty vehicle manufacturer and one light and heavy duty vehicle and engine testing company were used as case studies. Information regarding each company was collected from company representatives through interviews. During the interviews it was found that the companies had different maintenance structure and that the cell operators had different responsibilities. This resulted in that each company had different Mean Time To Repair (MTTR) and Mean Wait Time (MWT).

The different methods used by the two companies were summarized and compared to each other, to find potential improvement opportunities. The improvement opportunities were summarized together with two of the sub goals of the project: "What automation improvement could be beneficial for both case studies." and "An improvement opportunity had to be connected together with the automation system". From the improvement opportunities a function table was created, which main purpose was to satisfy the sub goals. The function table also aimed to improve the efficiency and utilization for both the companies.

From the function table an integrated report concept was created. The concept had the purpose to minimize the time spent on non-valuable work while speeding up the process of reporting malfunctions. This was performed by allowing cell operators to submit reports directly from the automation system.

Key words– Light and heavy duty engine testing, Test cells, Automation, Maintenance structure, Integrated report system

Acknowledgments

This report is a part of the master's degree program *Systems, Control and Mechatronics* at *Chalmers University of Technology.* The report is written by one student attending the program. The project was issued by the company AVL Nordiska List AB in Mölnlycke, Sweden.

The intentions of this thesis is to investigate two(2) case studies, compare the maintenance structure and the responsibilities of the operators while presenting improvement opportunities for both the case studies.

I would like to thank my supervisors from AVL, *Henrik Ernholm* & *Fredrik Dunert* for providing the opportunity to perform this thesis.

A special thanks to my examiner and supervisor *Martin Fabian*, Professor of Automation at the Department of Signals and Systems at Chalmers University of Technology for his enthusiasm and support during the project.

I would like to thank all the employees at AVL, your engagement and good humor made my time at AVL a pleasant one.

Lastly, I would like to thank all the company representatives from the two case studies. Without you the final outcome of this project would not have been the same.

Joe Furborg, Göteborg [August 2015]

Nomenclature

Commonly used words:

AVL	AVL Nordiska List AB
DPF	Diesel Particulate Filter
Down-time	Amount of time a cell is not producing valuable work.
Dyno	Dynamometer
FSN	Filter Smoke Number
ICE	Internal Combustion Engine
Log-files	Log-files summarize all the actions a piece of equipment performs. Often used during troubleshooting to find the source of a malfunction.
MSS	Micro Soot Sensor
MTTR	Mean Time To Repair
MWT	Mean Wait Time
OEM	Original Equipment Manufacturer
R&D	Research and development
TCO	Test Cell Operator
TCS	Test Cell Supervisor
TCE	Test Cell Engineer
TCR	Test Cell Responsible

Measurable exhausts:

CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbon
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Mixture of ditrogen molecules, NO and NO_2
O_2	Oxygen
PM	Particulate matter
PN	Particulate number
SO_2	Sulfur dioxide
Soot	Unburnt carbon particles in exhaust emissions

Exhaust measurement methods:

BAM	Beta attenuation monitoring
CD	Diffusion charging principle
CLD	Chemiluminescence detector
FID	Flame ionization detector
FTIR	Fourier transform infrared analyzer
GC-FID	Gas Chromatograph flame ionization detector
HCLD	Heated chemiluminescence detector
HFID	heated flame ionization detector
MPD	Magnetopneumatic Detector
NDIR	Non-Dispersive infrared analyzer
PMD	Paramagnetic detector analyzer
QCL	Quantum Cascade Laser
TEOM	Tapered element oscillating microbalance

Contents

1 Introduction

During the development of new vehicle models a variety of different tests are performed. The tests verify that each vehicle satisfies legislation's levels of emissions, durability as well as driving characteristic and performance. To perform these tests advanced test cells and equipment are required. However, one big obstacle with test cells of this kind is to achieve a high level of efficiency and utilization. One factor of decreased utilization is the unplanned stops of a test cell due to maintenance of the equipment and sensors.

1.1 Background

This project was issued by AVL Nordiska List AB, a test cell and engine testing equipment manufacturer and deliverer in Mölnlycke, Sweden. The project was conducted by one student from the master program Systems, Control and Mechatronics which is a master's degree from Chalmers University of Technology in Gothenburg.

1.2 Purpose

The goal and purpose was to review, evaluate and compare the maintenance structure of two OEM's test facilities, while providing improvement opportunities from the comparison. The improvements were supposed to connected to the automation system.

1.3 Precision of Questions

During the project the following questions were treated:

- Main Question:
  - How can the automation system be utilized to increase the total throughput.

- Sub Questions:
  - How was the maintenance structure of the two case studies.
  - What was the main difference in the structure of two case studies.
  - What improvement could be beneficial for both case studies.

- With an improvement implemented:
  - Will the overall efficiency and utilization of test cells be increased?
  - How can other similar installations benefit from this implementation?

1.4 Delimitations

The project had the following delimitations:

- The project was limited to two case studies.
- Onle functional and dynamical engine testing will be evaluated during this project.
- An improvement opportunity had to be connected with the automation system.
- Functional improvements were not to be implemented.

2 Methodology

This chapter presents the methods that were used to reach the project goals. The methods are presented in the order of there appearance in the paper.

2.1 Literature study

The test field area is a high technology area with a lot of different approaches. Thus, a literature study was required to achieve a greater understanding of the area and related work. A general overview of an test cell was developed by studying the book *Engine Testing*[1] by *Martyr, A.J.* and *Plint, M.A.*. The authors describe the fundamental parts of engine testing and also gives examples of where and how different setups and equipment can be used.

Furthermore, as shown by *Christiaanse W.R.* and *Palmer, A.H.* that scheduling of maintenance can severely increase the lifespan of equipment within production facility[2]. In their research different methods of scheduling are discussed as well as guidelines on how to implement scheduling of maintenance into the daily work.

It has also been show by recent studies that by working in flows the efficiency can be increase. The book *Detta är lean* by *Modig, N.* and *Åhlström, P.* describes how the work method of *Lean* can be implemented and how and where it can improve different production facilities[3].

2.2 Company visits

To be able to evaluate a system some general understand regarding the process is necessary. Since most test cells are incorporated in some kind of research and development (R&D) facility, close work with the staff necessary to gain vital information regarding the normal work flow. Several visits were made to two case studies. Case study A: one light duty vehicle manufacturing company. Case study B: one(1) light and heavy engine testing company with two facilities.

2.3 Data acquisition

Information on how the companies were working was required to be able to compare the companies. The information regarding the companies and there daily work was gathered together with operators and service personnel at the companies but also from AVL's own personnel. The data was collected via company visits, interviews and phone calls with the companies representatives. The representatives were connected to the daily work with the test cells.

2.3.1 Company Representatives

The information that was gathered from each case study was collected from selected company representatives. The representatives were selected by the project supervisors from AVL but also from the maintenance management at each case study. The representatives that were chosen were staff members who had extensive knowledge regarding their area of expertise. Each representative was also connected to the maintenance at each case study.

2.3.2 Interview method

To collect qualitative data from the company representatives interviews were conducted. The authors *DiCicco-Bloom, B.* and *Crabtree, B.F.* discusses two of the three commonly used interview methods, *Unstructured*, *Semi-Structure* and *Structured*. The authors present the methods in the article *The qualitative research interview* published in the book *Medical Education*[4]. The three(3) methods are presented and briefly described in the following bullet-list.

- Unstructured - Guided Conversation around the subject. No pre-made questions.
- Semi-Structured - Interview with pre-made questions. This method allows conversation around the subject.
- Structured - Interview with the same questions to every participant. This method does not allow conversation around the subject. Commonly used for surveys.

The interviews for this project used a mixture the of two different methods, unstructured and semi-structured interviews. The mixture of the two interview methods allowed the researcher to ask questions to the representatives while allowing the interview to go deeper into some subjects. An interview template that was used during the interviews can be found in the appendices, Appendix [A].

2.4 Comparison

The two case studies were carefully compared to each other in different aspects. The first comparison was a general comparison. Topics such as active industrial area, vehicle type and cell personnel were discussed and compared. Secondly the equipment was compared, and lastly the maintenance structure.

2.4.1 Highlights table

From the comparison, a highlights table was created. The table consists of highlights from the comparison. Each highlight has a number used to refer to each individual highlight later on. The highlights were a summary from the comparisons and presented how the case studies had solved each highlight. The table also shows the implications that corresponded to the similarities and differences between the different methods of each case study.

2.5 Synthesis

From the comparison, different areas were highlighted with corresponding implications presented. In these areas, the two case studies had similar or different methods to perform each task. A sub-goal of the project was to investigate improvement opportunities that would be beneficial for both companies. Hence, the project was limited, together with the supervisors from AVL, that such an improvement opportunity had to be connected to the automation system, rather then suggesting individual changes to each case study.

2.5.1 Improvement opportunities

From the highlights table certain highlights were selected. The selected highlights were highlights where the case studies had different methods to solve/perform the same task. An improvements table was created where the selected highlights were listed. For each highlight, there was one or more implications present due to the case studies' methods to solve that task, while the table presented improvements/solutions for each of the implications.

2.5.2 Function table

A function table was created from the improvement opportunities table. The function table was created together with one sub-goal as a common requirement, "What improvement could be beneficial for both case studies". The function table had a set of functions with different properties. Each function descended from the improvements table. Furthermore, each function was either required or wanted depending on how important that function was for the final improvements.

2.5.3 Integrated report concept

From the function table, a report concept was created. The concept aimed to reduce the time for the operators to send an error report. The report concept aimed to create a more standardized way to send and receive reports, while in the mean time it also aimed to even out the work flow in the production.

3 Automotive History and Testing

This chapter covers a history segment about the introduction of automotive cars in modern society, as well as a description of automotive testing and a general description of the equipment that is required. This is followed by a summary of the most common driving cycles, the task of the automation system and a typical layout of a test cell.

3.1 History

The beginning of the automotive era started with the steam-powered vehicles. The very first full-scale self-propelled steam-powered land vehicle was designed by *Nicolas-Joseph Cugnot* who in 1769 created the steam-powered tricycle[5]. The first designs of steam-powered vehicles had problems with maintaining the steam pressure and handling the water supply. However steam-powered vehicles were further developed and used throughout the 19th century and early parts of the 20th century. The internal combustion engine (ICE) replaced the steam-powered engines around the 20th century, as the commercial drilling and production of crude oil could supply petroleum as fuel for the engines. The first records however of using an ICE to propel a land vehicle was in 1807 by the Swiss inventor *François Isaac de Rivaz*[6]. The engine that he invented used a mixture of hydrogen and oxygen as a combustion fluid.

The concepts of the “modern car” however is considered to have been invented by *Karl Benz*, who in 1885 produced his *Motorwagen* in *Mannheim, Germany* by using an engine he earlier patented in 1879[6]. During the time between 1888 - 1893 Benz produced and sold 25 vehicles. In 1899, Benz & Cie. was the largest car manufacturer in the world with 572 vehicles produced that year. During early parts of the 20th century, manufactures all over the world began to mass produce cars via the new concepts of interchangeable parts and standardizing the production labor. A good example of this is how the *Ford Motor Company* managed to standardize their production line around 1914. As a result of the standardization, *Ford Motor Company* managed to increase their productivity and decrease the time between each vehicle produced. Thus became *Ford Motor Company* the largest car manufacturer at that time.

The modern car of today has a lot in common with the first automotive vehicles. The basic design and the major equipment still consists of the same parts, e.g Chassis, Wheels, Engine, Gearbox etc. However, often a variety of electronic systems are installed to aid the driver and to enhance the feeling of luxury. Furthermore, the modern automotive vehicles are guided by legislations and rules from government agencies and departments. These legislations and rules exist to ensure that each vehicle is safe to operate and do not harm the environment and its inhabitants via exhaust emissions. Vehicle tests are performed to ensure that each vehicle reaches certain legislation limits.

3.2 Automotive Testing

The modern automotive vehicles can be divided into three parts, Light duty, e.g Passenger cars, Heavy Duty, e.g Rock Trucks and last Off-road vehicles, e.g military cars, trucks and other vehicles. For each vehicle type are there different regulations and legislations applied. Throughout the 20-century where passenger cars were introduced as a means of transport, the variants of tests have been developed. During the "Muscle car era" from around the 1950's to 1980's, the driving factor of light duty testing was on engine power and performance, while the current driving factor of light duty testing is the emissions legislations, while Heavy duty and off-road testing are more focusing on durability and fuel economy. The most common areas of light duty testing can be found in Table [3.1]. Some more uncommon tests are altitude test and cold/warm climate testing.

Table 3.1: Automotive Testing Areas.

Area:	Test:
Power-train:	Drivability
-	Endurance
-	Emission
Chassis:	Aero-Dynamics
-	Emission
-	Indication
-	Milage
Engine:	Acoustics
-	Dynamic
-	Durability
-	Emissions
-	Fuel economy
-	Static
Safety:	Crash tests
-	Detection systems

3.3 Emissions Legislation

Regulations and legislations are used to certify that vehicles are safe to drive and do not emit too much emissions. There exist different certifications depending on where a vehicle manufacturer want to market the vehicle. E.g if a manufacturer want to market a light duty vehicle in Europe then the vehicle needs to fulfill the emissions standards *Euro 1-6*[7]. Similar standards exists for China, USA, and India. For these three areas, the following standards used: *China I-V*[8], *US Tier 1-3*[9] and *Bharat 1-4*[10]. For heavy duty vehicles in Europe, the *Euro I-VI*[11] standards are used.

These standards regulate how much Carbon Monoxide (CO), Nitrogen Molecules (NO_x), Hydrocarbon (HC), Particulates Matters (PM) and Particulates Numbers (PN) that each vehicle is allowed to emit. The following tables [3.2] and [3.3]. show the evolution of the Euro 1-6 and I-VI standards, when it comes to use, fuel, emission limits, (PM) and (PN). The standards are used together with driving cycles, which are a standardized way to simulate road and speed variations. This is performed to create comparable results between each run or test. See Section [3.4] for a more thorough description of driving cycles.

Table 3.2: Evolution of the light duty standard: Euro 1-6.

Standard:	Date:	CO	NO_x	HC	NO_x+HC	PM	PN
		[g/km]					[#/km]
Compression Ignition (Diesel)							
Euro 1	1992.07	2.72	-	-	0.97	0.140	-
Euro 2	1996.01	1.00	-	-	0.90	0.100	-
Euro 3	2000.01	0.64	0.50	-	0.56	0.050	-
Euro 4	2005.01	0.50	0.25	-	0.30	0.025	-
Euro 5a[12,B]	2009.09	0.50	0.18	-	0.23	0.005	-
Euro 5b[13,C]	2011.09	0.50	0.18	-	0.23	0.005	$6.0 * 10^{11}$
Euro 6[13,C]	2014.09	0.50	0.08	-	0.17	0.005	$6.0 * 10^{11}$
Positive Ignition (Gasoline)							
Euro 1	1992.07	2.72	-	-	0.97	-	-
Euro 2	1996.01	2.20	-	-	0.5	-	-
Euro 3	2000.01	2.30	0.15	0.20	-	-	-
Euro 4	2005.01	1.00	0.08	0.10	-	-	-
Euro 5[13,C]	2009.09	1.00	0.06	0.10	-	0.005	-
Euro 6[13,C]	2014.09	1.00	0.06	0.10	-	0.005	$6.0 * 10^{11}$

Table 3.3: Evolution of the heavy duty standard: Euro I-VI.

Standard:	Date:	CO	THC	NMHC	CH_4	NO_x	PM	NH_3
		[mg/kWh]						[ppm]
Compression Ignition (Diesel)								
Euro I	1992.01	4.50	1.10	-	-	8.00	0.612	-
Euro II	1996.10	4.00	1.10	-	-	7.00	0.250	-
Euro III	2000.10	2.10	0.66	-	-	5.00	0.100	-
Euro IV	2005.10	1.50	0.46	-	-	3.50	0.020	-
Euro V	2008.10	1.50	0.46	-	-	2.00	0.020	-
Euro VI[14,D]	2013.01	1.5	0.13	-	-	0.40	0.010	10
Positive Ignition (Gasoline)								
Euro III	2000.10	5.45	-	0.78	1.60	5.00	0.160	-
Euro IV	2005.10	4.00	-	0.55	1.10	3.50	0.030	-
Euro V	2008.10	4.00	-	0.55	1.10	2.00	0.030	-
Euro VI[14,D]	2013.01	4.00	-	0.16	0.50	0.46	0.010	10

3.3.1 Light Duty - Engine Testing

Light Duty - Engine testing can be divided into three major sections: Dynamic, Static and Durability. Each section can be divided into a set of sub-categories of test areas. The dynamic and static tests are generally performed to test an engine's performance and emissions properties, while durability tests evaluate how durable the engine is. See fig [3.1] for an overview of the test areas.

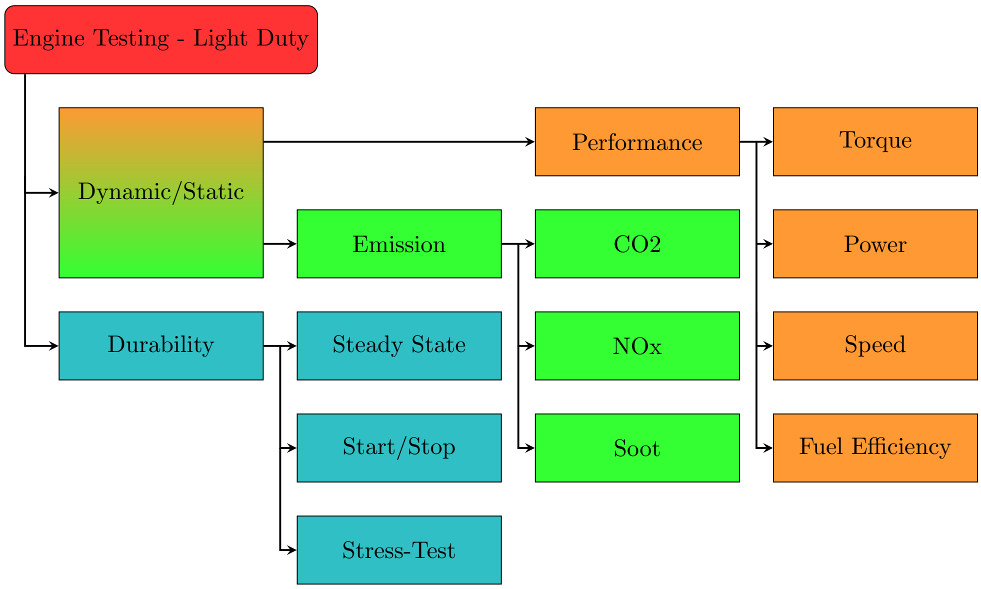


Figure 3.1: Flowchart of Engine Testing sections.

3.3.2 Light Duty - Equipment

To be able to collect reliable measurements, commonly high-end equipment are used. Each piece of equipment is especially developed to measure one specific parameter e.g CO_2 emissions or rated torque at a certain speed. Table [3.4] shows some of the equipment and methods that are commonly used in a test cell as well as the corresponding area. The table presents only performance and emission equipment and methods. However, durability testing of an engine is commonly performed by evaluating how well the engine can handle long time driving, e.g driving at constant speed for a long time, multiple cold/warm-starts and stops of the engine. But also stress tests such as pushing the engine to produce maximum power and torque for a certain amount of time or until the engine breaks.

Table 3.4: Commonly Used Equipment and Methods for Engine Testing.

Test area:	Equipment:	Type:
Performance	Dynomometers:	Water Brakes
-	-	Hydrostatic Dynomometers
-	-	Asynchronous motors
-	-	Eddy-Current Dynomometers
-	Fuel Consumption	Volumetric Gauge
-	-	Gravimetric Gauge
-	Speed	Tachometers
-	-	Encoders
Emissions	CO_2	Fourier transform infrared analyzer (FTIR)
-	CO_2 / HC / SO_2 / SF_6	Non-Dispersive infrared analyzer (NDIR)
-	CO_2 & HC	Flame ionization detector (FID)
-	CH_4	Gas-Chromatograph FID (GC-FID)
-	CO_2 & NO_x	Paramagnetic detector analyzer (PMD)
-	NO_x	Chemiluminescence detector (CLD)
-	-	Quantum Cascade Laser (QCL)
-	THC	Flame ionization detector (FID)
-	O_2	PMD
-	THC & O_2	FID + PMD
-	Soot	Diffusion charging principle (DC)
-	-	Photoacoustic
-	-	Opacimeter
-	Particulate matter	Weighting filter paper
-	-	Beta attenuation monitoring (BAM)
-	-	Tapered element oscillating microbalance (TEOM)
-	Particulate matter	Volatile particle counter

3.4 Driving Cycles

Driving cycles are commonly used to test the performance and emission of an engine or vehicle. The driving cycles are a standardized way to simulate road characteristics together with speed variations. There exist a lot of different driving cycles with different characteristics depending from where the driving cycle has been developed. The European driving cycles *EUDC* and *NEDC* represent European roads and characteristics while *FTP-75* represent highways in the USA and *10-15 Mode* & *JC08* are light duty city driving in Japan. The following figures [3.2], [3.3], [3.4], [3.5] and [3.6] show the driving cycles from Europe, USA and Japan. The figures show how the speed of the vehicle varies depending on the time. The figures also have a short description that contains information regarding when the driving cycle was first introduced and what type of road characteristic the driving cycle shall represent.

UDC/ECE - Urban Driving Cycle: The UDC was invented in $1970's$ and represent typical driving at the time. The driving cycle has a maximum speed of 50 km/h and represents typical driving conditions in major European cities.

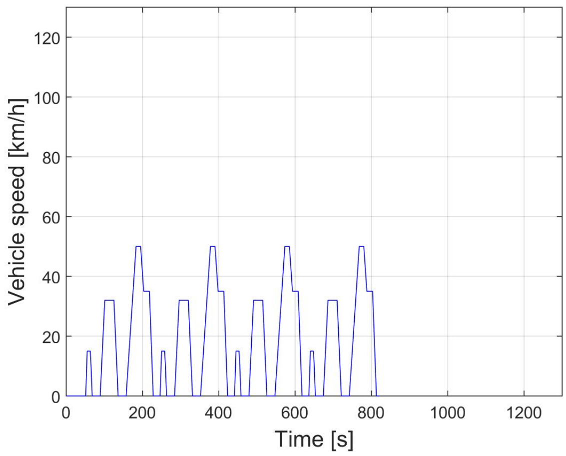


Figure 3.2: Driving Cycle - UDC.

EUDC - Extended Urban Driving Cycle: The EUDC was invented in $1990's$ and represents European highway driving, i.e a more aggressive drive style and reaches 120 km/h. There is a version available for low-powered vehicles, which reaches 90 km/h as maximum speed.

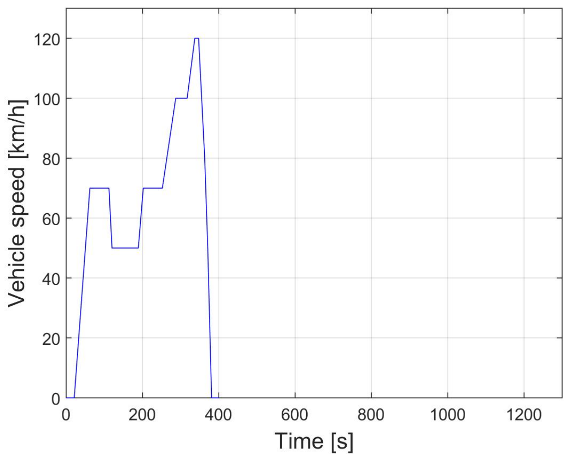


Figure 3.3: Driving Cycle - EUDC

NEDC - New European Driving Cycle: The NEDC is the combination of four UDCs and added one EUDC at the end. This driving cycle was introduced in 1997 to represent the driving of a typical European vehicle at the time. Currently, the NEDC is used for emissions legislations.

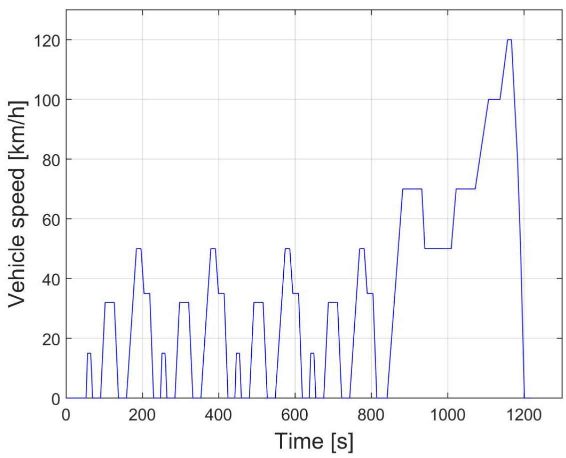


Figure 3.4: Driving Cycle - NEDC

FTP-75 - Federal Test Procedure: The FTP-75 is a driving cycle which represents city driving in the USA. It was developed by *EPA - Federal Test Procedure* in USA and reaches a maximum of 92 km/h. The FTP-75 is a more aggressive driving cycle then the European driving cycles.

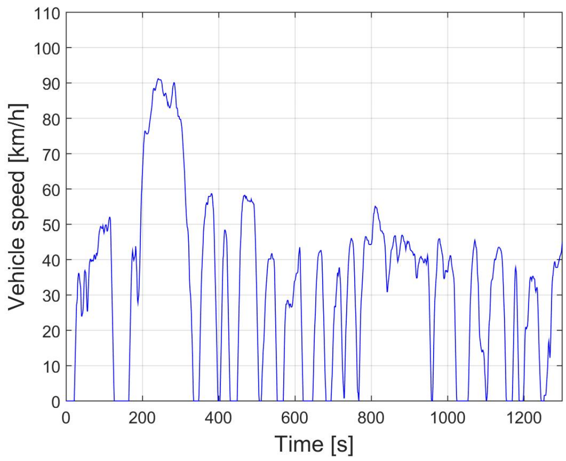


Figure 3.5: Driving Cycle - FTP 75

$10-15$ **Mode & JC08 - Japan Automotive Industry** The Japanese driving cycles are some what similar to the UDC driving cycle but do however represent Japanese road characteristics and speeds instead.

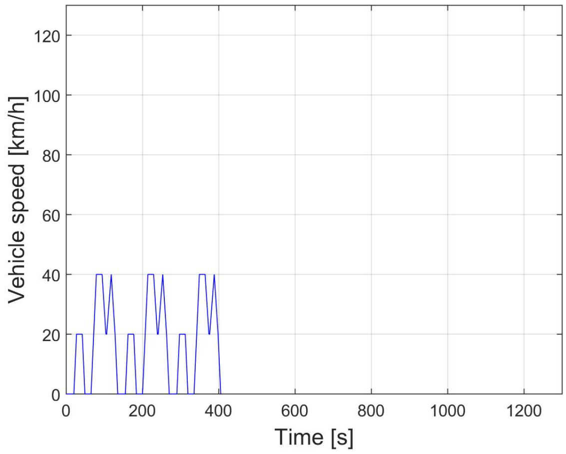


Figure 3.6: Driving Cycle - 10-Mode

3.5 Automation Software

The automation system have the important role to control and collect measurements from the tests that are executed. This is often performed by preparing and executing a drive cycle while measuring the corresponding results from the test equipment. The automation system utilizes the driving cycle as a set-point reference for the velocity, while an operator applies a control signal to the car's throttle to achieve the desired velocity as the driving cycle.

During the test the different measurements display on several screens in the room where the operators are working. When a test has finished, then the measured data is stored on a central database. This is to enable easy access of data and to enable the option to search and compare previous results with each other.

The automation software can be used together with different simulation software, to simulate road and vehicle characteristics. The simulation software then requires a digital model of the vehicle. By adding real world physical characteristics such as gravity, friction, air- and rolling resistances to the simulation, the digital model can be enhanced to represent a real world vehicle. With an appropriate model ascending and descending gradients can be simulated, but also tilted roadways.

While the main function of the automation system is to control and measure the results from the test, it is also connected together with a variety of subsystems. Subsystems such as fire and evacuation systems, power failure systems, but also some safety systems to ensure that unauthorized personnel do not enter the test cell during the execution of a test.

3.6 The Test Cell

A test cell can be built up in many different ways, but generally will it consist of two to three rooms[1]. One room is the *test cell* for the object under test. Another room is the *operators room* for the operators and computers. A third room is also common to have where the analyzing equipment is stored, such as emissions analyzers, dilution chambers and gas storage. These kind of equipments are ofter stored in a separate room due to the high levels of sound that the equipment emits during operation.

The test cell room usually has an door or another opening for inserting the object under test. The door is also used to take in and out equipment. Different equipment can be installed in the test cell. The type of equipment depend on the testing objective of the cell. The most common equipment systems to have installed are fuel systems, emission systems, dynomometer, ventilation and temperature treatment systems.

Within the operator room are there often computers to observe and control as well as review the measurements of the current test. See figure [3.7] for an overview of a fictional test cell.

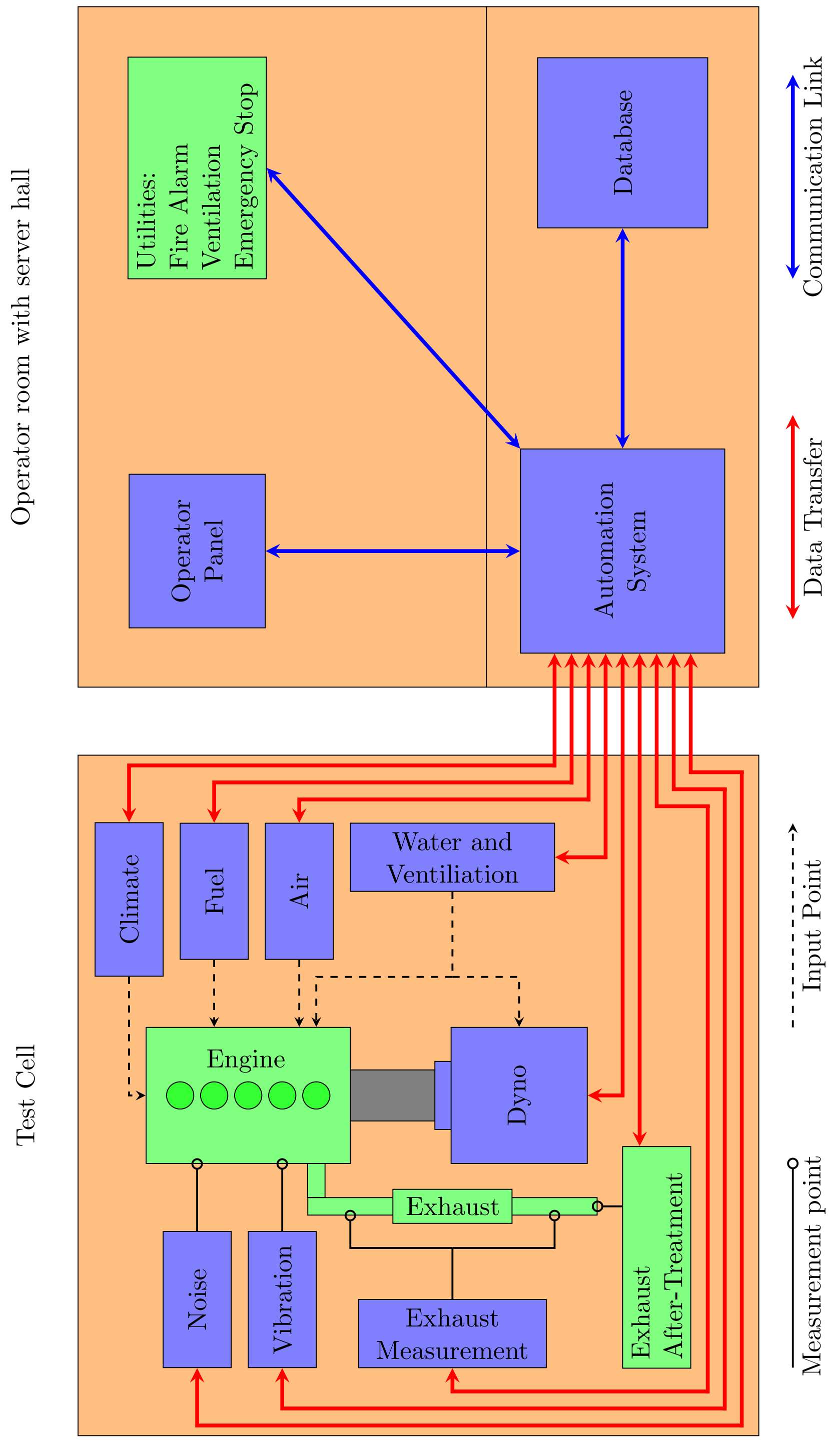


Figure 3.7: Overview of a fictional Test Cell

4 Case Study A

In this section the first case study is presented. First a company description, followed by the test cell equipment composition and the corresponding maintenance description of the equipment. Highlights are presented at the end of this section to give an overview of the company and the maintenance. The information from company A was gathered together with company representatives who were: a Service Engineer, a test cell operator (TCO), a test cell supervisor (TCS), two maintenance personnel and the manager from the maintenance department, as well as the test field administrator.

4.1 Company Description

Company A was a light duty vehicle manufacturer located in Sweden. The manufacturing site had ongoing production and testing throughout the week days and produced vehicle models ranging from *sedans*, *estates* to *SUV's*. The company had several different R&D departments where engineers were working on developments of existing and new car models. Company A had a particular department devoted to vehicle testing[15]. Within this department different aspects of the vehicles were tested. The tests ranged from *Predevelopment - Single Cylinder*, *Dynamical*, *Functional*, *Power Train*, *Chassis* to *Durability* tests.

The cells were commonly manned by one to three TCOs and one TCS. The TCS was the person who ordered/planned the tests in the cell, while the TCO carried out the actual test. The TCO also checked that the engine was equipped with the right sensors and valves while also checking that the required equipment was present in the test cell. Vehicle testing was commonly performed during the week days but the company had plans to extend testing into the weekends as well.

The tests were performed by the use of driving cycles, see Section [3.4] for descriptions of each driving cycle. Some steady state tests were also used to evaluate the performance and exhaust during the dynamical testing. Functional testing was however used to calibrate the engines[16]. Each test cell had different development objectives, the objectives could vary from evaluating the engine's *Durability*, *Fuel Economy*, *Emissions* to measurements of *Performance*. The different development objectives implied that different cells required different types of equipment.

The test organization of company A can be seen in Figure [4.1]. Test production where divided in three divisions[17], *development*, *testing* and *service*. The development department worked on new engine models and calibrations and could order test from the testing department. The *testing* department was the personnel who executed the test, i.e the TCOs and the TCSs. The personnel was also in charge of reporting deviations to the service department. The *service* department had the responsibility to solve the deviations that the TCOs and TCSs had encountered[18]. The Service department ensured that the right technician was sent to investigate the problem and solve the issue. The technicians from the service department were also in charge of performing the maintenance of the equipment and cell.

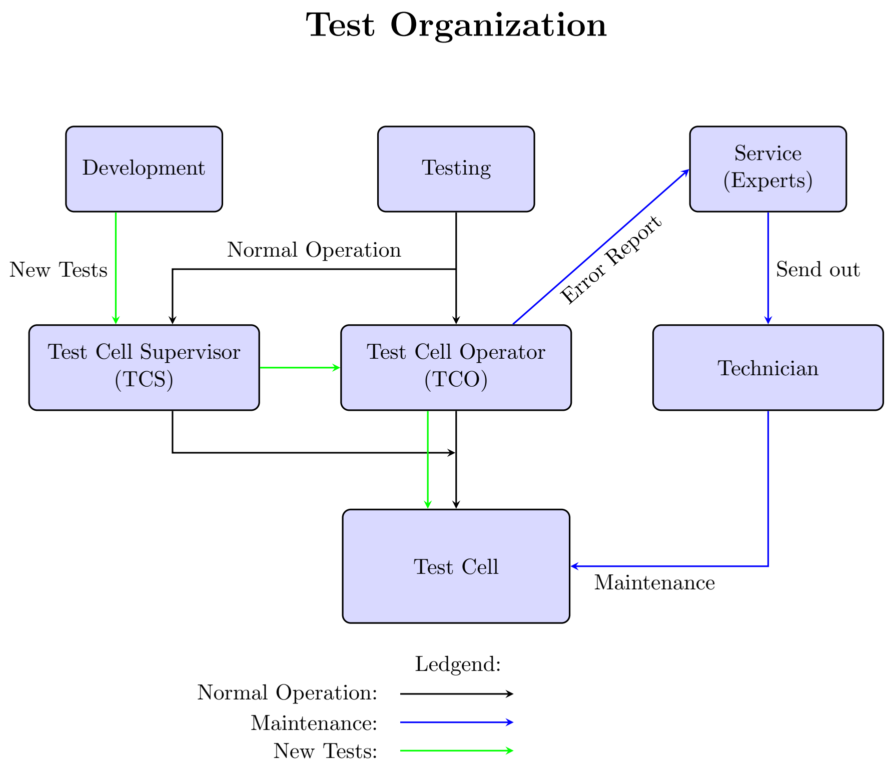


Figure 4.1: Case A: Structure

4.2 Engine Test Cell Equipment Composition

Company A had a composition of seventeen engine testing cells where five cells were dynamical-testing cells and twelve cells were functional-testing cells[19]. The dynamic cells were mainly used to evaluate developments on the combustion and calibration of the engine and exhausts[16].

The following tables [4.1] and [4.2]. show an overview of the equipment that was installed at company A's engine test cells[19]. The dynamical cells are denoted by a *D* while the functional cells are denoted by a *F*. The tables also show if the cells were mainly handling gasoline or diesel engines. The equipment in the tables are marked with colors depending on the type of equipment. Equipment marked by green are *Emissions* systems, *Conditioning* systems are blue, *Measurement* systems are red and *Utility* systems are yellow. Description of each equipment can be found in Section [6.1], together with descriptions of the techniques that each equipment uses.

Table 4.1: Case A: Dynamical Cells

Equ. / Cell	Fuel:	AVL 415s	AVL 439	AVL 483	AVL 489	Horiba SPCS	AVL i60 Sesam	Horiba Mexa 7000	AVL 753c	AVL 735s	AVL 364c	AVL 622
D-1	D	✓	✓	✓	-	✓	✓	D/CVS	✓	✓	✓	✓
D-2	G	✓	✓	✓	✓	-	✓	DEGR	✓	✓	✓	✓
D-3	D	✓	✓	✓	✓	-	✓	D/CVS	✓	✓	✓	✓
D-4	G	✓	✓	✓	✓	-	✓	DEGR	✓	✓	✓	✓
D-5	D	✓	✓	✓	✓	-	✓	D/CVS	✓	✓	✓	✓

Table 4.2: Case A: Functional Cells

Equ. / Cell	Fuel:	AVL 415s	AVL 439	AVL 483	Horiba Mexa 7000	AVL 753c	Inhouse Conditioning	Inhouse Coriolis	AVL 735s	AVL 364c	AVL 622
F-1	D	✓	✓	✓	DEGR	-	✓	✓	-	✓	✓
F-2	D	✓	✓	✓	DEGR	-	✓	✓	-	✓	✓
F-3	D	✓	✓	✓	DEGR	-	✓	✓	-	✓	✓
F-4	D	✓	✓	✓	DEGR	-	✓	✓	-	✓	✓
F-5	G	✓	✓	✓	D	-	✓	✓	-	✓	✓
F-6	G	✓	✓	✓	D	-	✓	✓	-	✓	✓
F-7	G	✓	✓	✓	D	-	✓	✓	-	✓	✓
F-8	G	✓	✓	✓	D	-	✓	✓	-	✓	✓
F-9	D	✓	✓	✓	D	✓	-	-	✓	✓	✓
F-10	G	✓	✓	✓	D	✓	-	-	✓	✓	✓
F-11	D	✓	✓	✓	DEGR	✓	-	-	✓	✓	✓
F-12	G	✓	✓	✓	DEGR	✓	-	-	✓	✓	✓

Color Code:

Emission	Conditioning	Measurement	Utility

4.3 Case A - Maintenance

Company A had different levels of scheduled maintenance that were either performed by the TCOs and in-house service personnel or contracted service personnel[20]. The maintenance was divided into daily, semi-annual and annual maintenance. The difference between the maintenance depended on the type of cell, e.g the consumed fuel and the types of tests that were performed. See Section [E]. for maintenance routines required for each piece of equipment.

Some unplanned maintenance was present due to malfunctions on the equipment and utilities of the test cells. When a malfunction occurred, then the TCO checked the automation system for errors and also checked the relevant equipment for inaccuracies. The TCO had to fill in an error-report in a computer program. The program was not available on the computers that were used to monitor the test cell but rather on a separate computer in the operators room[15]. The program stored every report in a central database for easy access and was used to summarize production time and downtime of each cell.

The error-reports had to contain information regarding which cell, the equipment and what kind of malfunction, but also other vital information such as unusual noises and heat increments. The service department reviewed the error-report, when it had been stored on the database. The service department then contacted the correlated maintenance department, e.g emissions, fuels, facilities, who then sent a technician to investigate the malfunction. If an incomplete or inaccurate error-report was obtained by the service personnel, then the service department or the technician had to investigate the malfunction further before being able to solve the issue[17].

The daily maintenance was mainly performed by the TCOs rather than by the service personnel, since the daily maintenance could often be performed without having to disassemble or remove the equipment. The tasks of the daily maintenance ranged from changing an equipments air filter to purging of emissions equipment[21].

At the semi-annual and annual maintenance skilled technicians and service personnel were required to perform a more thorough maintenance. It was often required to shut down the entire cell for one to two weeks depending on the extent of the maintenance. Calibration of the equipment was also performed at the end of the maintenance period. During the maintenance period the equipment either was removed from the cell or the maintenance was performed on the equipment in the cell. This was due to that the equipment either was to big and/or to heavy to be able to remove it from the cell. If the equipment could be removed from the cell, then the technician brought the equipment to a workshop where maintenance could be performed. Contracted personnel could be brought in to assist in the maintenance, usually to assist in the maintenance of some specific equipment, due to their knowledge regarding the equipment. During the time that the cells were shut down, the cell operators were often sent to business related presentations and seminars to further educate the personnel.

Company A had maintenance documents/protocols that contained detailed information regarding which part/parts that were required to be cleaned, repaired or replaced[17]. Generally was there one document/protocol per equipment, which contained steps that was supposed to be performed during the maintenance. The documents/protocols had been constructed from the maintenance tasks described in the supplied operating manual for each device. The document and protocols had also been further developed throughout years of use of the equipment, to ensure that the equipment was maintained in a proper way. The document/protocols were updated each time something changed in the manual or if a technician found a better way to perform the maintenance.

Highlights from Company A

- Production of their own vehicles.
- Owner of the test cells.
- Planned maintenance.
- Each cell had a defined testing objective.
- Personnel:
  - Own TCO and TCS.
  - Own service departments with service technicians.
  - Leased external technicians.
  - Came from production line.
- Good opportunity to follow up on errors and to measure statistics, due to computer program.

5 Case Study B

In this section the second case study is presented. First a company description, followed by the test cell equipment composition and the corresponding maintenance description of the equipment. Highlights are presented at the end of this section to give an overview of the company and the maintenance. The information from company B was gathered together with company representatives who were: a test cell engineer, a maintenance person and the manager of the service department.

5.1 Company Description

Company B was an engine testing company located in Sweden. The company had no vehicle production of their own, but rather performed engine tests for their customers[22]. The company worked with both light and heavy duty engines. However, the majority of the vehicles and engines that were tested were heavy duty vehicles and engines. The company had their own test cells located at two different locations where different tests were conducted at each site.

The company was able to conduct tests on both large heavy duty trucks as well as light duty vehicles. This was possible due to the size of the test cells and the equipment available. The company had the option to modify the cells after the customer's needs. With the option to modify the cells came a high flexibility to perform different tests. Each cell did not have a designated development objective, since the customers could order different types of tests from the company.

The company was able to perform tests ranging from *Predevelopment - Single Cylinder*, *Dynamical*, *Functional*, *Electric Vehicles Power Train*, *Chassis* to *Durability* within the company's test cells[23]. Furthermore, the company had the option to lease there personnel to other companies and customers to perform test for the customer's at the costumers cells.

Each test cell was usually manned by two to three test cell engineers (TCE) and one(1) test cell responsible (TCR). The TCEs were responsible for the test as well as lesser services and calibration of the equipment[23], while TCR was responsible for the communication with the customer, planning of tests, maintenance and calibration[22]. The TCR also ensured that the cell was equipped with the right equipment for each test. The TCR had usually a small budget, which enabled the TCR to do smaller purchases such as additional tools or smaller improvements without having to consult the work management. This helped the TCE to perform their daily tasks easier and faster than before.

The overall organization of company B is described in Figure [5.1]. Test production was divided into three parts: *Development*, *Testing* and *Service*. The *development* department worked on developments of new devices and further developments of existing devices and also testing methods. The *Development* department could also order tests from the testing personnel to confirm theories and thoughts on new devices and setups. The *Testing* department was the operators who were in charge of the tests. The test personnel did some smaller maintenance tasks but mainly performed the tests that were ordered. The *Service* department consisted of experts in various fields[22&24], areas such as emission, fuel, facilities etc. When the test personnel had problems with some equipment or required further knowledge of some equipment, then the TSE or TSR contacted the service department. The service department then sent a technician who could solve the problem. The service personnel also performed the majority of the service of the equipment, while the TCE and TCR participated in the service.

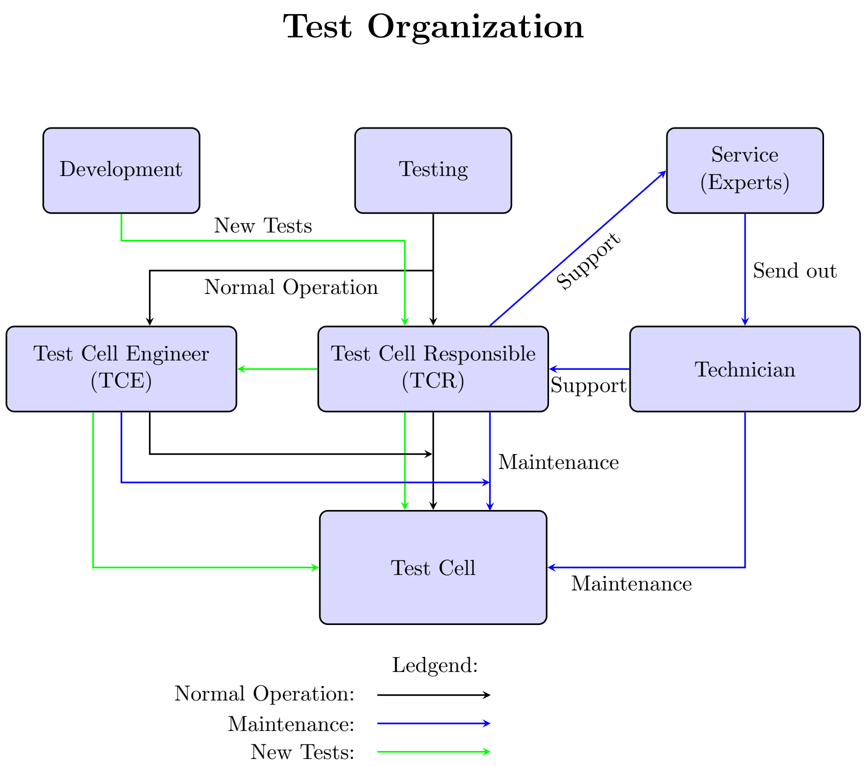


Figure 5.1: Case B: Structure

5.2 Engine Test Cell Equipment Composition

Company B had two testing sites which were mainly used for two types of test, dynamical and functional. The first site *B1*, mainly performed dynamical tests while the second site *B2*, mainly performed functional tests. Site *B1* had nine test cells where five were used for engine testing while site *B2* had seven test cells where six cells were used for engine testing and one(1) cell was used for single cylinder tests.

The following tables [5.1] and [5.2] shows an overview of the engine test cells of company

B and their equipment installed at the company[23]. The test cells at the first site are denoted by *B1* while the test cells at the second site are denoted by *B2*. The tables also show if the cells were mainly handling gasoline, diesel or alcohol fuels. The same color coding is present as in Case Study A, see Section [4.2], where *Emissions* systems are green, *Conditioning* systems are blue, *Measurement* systems are red and *Utility* systems are yellow. Description of each equipment can be found in Section [6.1] together with descriptions of the techniques that each equipment uses.

Table 5.1: Case B: Dynamical Cells

Equu. / Cell	Fuel:	AVL 415s	AVL 439	AVL 478	AVL 483	AVL 489	AVL DiCOM	Horiba MEXA 9000	AVL I60 Sesam
B1-1	A	-	-	-	-	-	-	✓	-
B1-2	D	✓	✓	✓	✓	✓	-	D/CVS	-
B1-3	G/D	-	-	✓	✓	✓	-	-	-
B1-4	A	-	-	✓	✓	✓	-	-	✓
B1-5	G/D	-	-	-	✓	-	-	-	-
Mobile Equ:	G/D/A	✓	✓	✓	✓	✓	✓	-	✓
Equ. / Cell	Fuel:	AVL 753c	AVL 364c	AVL 406	AVL 735s	AVL 740	AVL 442	AVL 622	AVL AMA 4000
B1-1	A	✓	✓	-	✓	-	-	✓	-
B1-2	D	-	✓	-	-	✓	-	✓	-
B1-3	G/D	-	✓	-	-	✓	-	✓	✓
B1-4	A	✓	✓	-	✓	✓	-	✓	-
B1-5	G/D	✓	✓	-	✓	-	-	✓	✓
Mobile Equ:	G/D/A	-	-	✓	-	-	✓	-	-

Color Code:

Emission	Conditioning	Measurement	Utility

Table 5.2: Case B: Functional Cells

Cell \ Equ.	Fuel:	AVL 415s	AVL 439	AVL 478	AVL 483	AVL 489	Horiba MEXA 9000	AVL I60 Sesam
B2-1	G/D/A	-	-	-	-	-	✓	-
B2-2	G/D/A	-	-	-	-	-	✓	-
B2-3	G/D/A	-	-	-	-	-	✓	-
B2-4	G/D/A	-	-	-	-	-	✓	
B2-5	D	-	✓	-	✓	-	-	-
B2-6	D	-	✓	-	✓	-	-	
B2-7	D	-	✓	-	✓	-	-	-
Mobile Equ:	G/D/A	✓	✓	✓	✓	✓	-	✓

Cell \ Equ.	Fuel:	AVL 753c	AVL 364c	AVL 735s	AVL 740	AVL 442	AVL 622	AVL AMA 4000
B2-1	G/D/A	-	✓	-	-	✓	-	-
B2-2	G/D/A	-	✓	-	-	✓	-	-
B2-3	G/D/A	-	✓	-	-	✓	-	-
B2-4	G/D/A	-	✓	-	-	✓	-	-
B2-5	D	-	✓	-	✓	-	✓	-
B2-6	D	-	✓	-	✓	-	✓	-
B2-7	D	-	✓	-	-	-	-	-
Mobile Equ:	G/D/A	-	✓	-	-	-	-	✓

Color Code:

Emission	Conditioning	Measurement	Utility

5.3 Planned and Flexible Maintenance

Here follows a description of the maintenance of the equipment and facilities of company B's engine test cells. The maintenance of company B's equipment and test cells consisted of a mixture of planned and flexible maintenance[22]. Different maintenance tasks were performed depending on if the maintenance was planned or flexible. See Section [E] for maintenance routines required for each piece of equipment.

The planned maintenance contained maintenance of equipment and facilities at certain periods, annual and semi-annual. At these instances the dynomometer together with bearings were lubricated, and the filters for the ventilation and conditioning systems were changed. The condition of the facilities was also checked. The safety system was also checked, functionality test was performed for the fire and evacuation systems, gas-leak alarms and ventilation and conditioning systems.

Calibration of the equipment was scheduled at predetermined dates. However, the TCR had an option to change the date of the calibration up to two weeks before and after the planned calibration date[24]. This adjustment helped TCEs and TCRs to perform the calibration at a more fitting moment, such as when the customer did not have as many tests to perform.

The flexible maintenance was performed when a maintenance notification was displayed either at the automation system's screens or on the inbuilt screen on the equipment. Usually this occurred 100 hours before the maximum operation time was reached. The TCR then contacted the service department, who together planned the maintenance. Smaller devices were removed from the test cell and replaced by mobile units to not lose valuable operation time[22]. Maintenance of larger equipment were performed in the cell at a time that disturbed the production the least.

For short periods of time, a variety of different tests could have been performed in each cell. This required flexibility in the cells, equipment and staff, but also the maintenance. Maintenance was for instance not performed on devices that had not been used since the last maintenance, since it was considered as unnecessary waste of time and staff when the equipment would certainly still work[22].

When a deviation in the cell or equipment had been detected, company B had a protocol for how to handle the deviations. First, the test personnel the responsibility to try to solve the deviation before contacting the service department[22]. This helped the personnel to achieve a greater understanding of how the cell works and could thus help the customer faster and more efficiently. If the TCEs and TCRs could not solve the deviation by themselves, then the service department was contacted to solve the deviation.

The service department then took over the responsibility of the deviation and had to solve the deviation or send an expert with the required knowledge. If the test personnel knew what the source of the problem was, but could not handle it by themselves, then the personnel could contact the required expert directly instead of contacting the service department. This was to avoid time consuming intermediaries and as quickly as possible get back to testing.

Whenever a deviation had been detected or solved, a deviation report was sent to the service department. The deviation report contained vital information regarding which cell, what equipment and other vital information. Vital information could be observed unusual heat increment and increasing noise levels. When the deviation report was reviewed by the service department, then an excel sheet that was available online, was updated with the information from the deviation report. The excel sheet then contained the information from the deviation report but also showed the next step to solve the deviation and where the responsibility was for the deviation [22], e.g if the operators had to solve it by themselves or if the service department had to call in an expert or if parts were required to be ordered from the equipment manufacturers. The operators had access to the excel document from the computers in the operator's room and could thus see the next step in the process of solving the deviation.

During the course of time, the excel sheet had grown into a database containing every deviation but also the steps which solved each deviation. From the excel sheet was statistics of production time and downtime for each cell summarized. This database was used to facilitate purchases of new equipment. The database was used to find the correlation between the downtime of the cell and the amount of malfunctions of a specific device. This facilitated for the TCR to highlight the benefits of purchasing new equipment or to implement improvements in the cell.

Highlights from Company B

- No production of their own.
- Owner of their test cells.
- Flexible maintenance.
- Flexible test cells.
- Mobile test equipment available.
- Personnel:
  - Own TCE and TCR.
  - Support department with experts.
  - Leased the TCEs and TCRs to other companies.
  - Had often a higher education, Bachelor/Master of science.
- Deviation and improvement report system.

6 Engine Testing Equipment

This section describes the equipment and the techniques that each equipment utilizes. The maintenance descriptions for each equipment can be found in Appendix [E]. The structure of this section uses the color coding from tables [4.1, 4.2, 5.1 and 5.2]. First, emissions equipment are described, second the conditioning equipment and third the measurement equipment and last the utility equipment.

6.1 Equipment description

The equipment that was installed at the two case studies are presented here together with the techniques that the equipment utilizes.

6.1.1 Emission Systems

The emission equipments consisted of different devices and units that were used to measure and evaluate different emissions in the test cell. Gaseous emissions from the exhaust but also the particulates and opacity of the emissions.

AVL-415s, Smokemeter

The *AVL-415s Smokemeter* is a soot measurement unit which uses the filter paper method to measure the concentration of soot in diesel exhaust emissions[25]. The emission sample is led from the engine's exhaust pipe into the device and a defined sampling volume passes through a clean paper. The soot particles then stick to the paper, while a microprocessor analyzes the amount of soot via a photoelectric measuring head. The result of the measurement is presented as Filter Smoke Number (FSN). The FSN is a value of the concentration of soot in the sampled volume either in % or in mg/m^3. The measurements of soot can both be performed upstream and downstream of the diesel particle filter (DPF).

AVL-439, Opacimeter

The *AVL-439 Opacimeter* measures the opacity of the emissions from an engine's exhausts[26]. The method that is used to measure the opacity is light against a non-reflecting surface. A defined sampling volume of exhaust gas is confined in the equipment as a light source is lit and a receiver registers the quantity of light that is passing through the exhaust gas. The result of measurement is presented as percentage of light that passed through the gas.

AVL-478, Smart Sampler

The *AVL-478 Smart Sampler* is used to measure the mass of particles in exhaust emissions[27]. The method that is used is a partial dilution system together with a gravimetric sampling system. The device consists of four main parts, the main cabinet, filter cabinet, dilution and probe tunnel and last the software to control the device. The main cabinet holds the majority of the electronics and mechanics. The filter cabinet holds the filter for the particulates, dilution air, conditioner and blowpass air. A sample of exhausts emissions is collected from a connection on the exhaust system. The sample is led to a heated probe followed by a dilution of air, where the probe heats the sample and dilutes the sample with air. The sample is then conditioned, where water- and oil residues and large particulates are removed. The *AVL478 Smart Sampler* can then perform a measurement without impurities in the sample.

AVL-483, Micro Soot Sensor

The *AVL-483 Micro Soot Sensor* (MSS) measures the soot particulates in exhaust emissions from diesel and direct injected gasoline engines. The unit uses the photoacoustic method to measure the amount of soot in the exhausts emissions[28]. The photoacoustic method consists of irradiating the soot particulates with modulated light. The radiation causes the soot particles to expand and contract which produces a sound wave. A microphone captures the sound wave. The sound level corresponds to the number of soot particulates in the emissions.

AVL-489, Particle Counter

The *AVL-489 Particle Counter* measures the amount of non-volatile particulates in the exhaust emissions[29]. The particle counter is built up of two main systems, a conditioning system and the particle counter. The conditioning system consists of three parts, two dilution chambers and one evaporation tube. The emissions are led into the first dilution chamber where all particulates larger then $2.5\mu m$ are eliminated and preheated to $150°C$. This stabilizes the particle concentration. The remaining emissions are transported to the evaporation tube, where the emissions are even further heated to $300 - 400°C$ to convert the volatile particulates into a gaseous form. The heated gas is transported to the second dilution chamber to prevent condensation and absorption of volatile substances. The measurement system then measures and counts the remaining particles in the emissions using the light scattering method.

HORIBA-SPCS, Solid Particle Counter System

The *HORIBA-SPCS* is a two-way dilution measurement system used to measure the emission particulates in after-treatment systems[30]. The unit has two dilution chambers (hot and cold) that treats the controlled measurement volume, but also one evaporation unit and a condensation particle counter. The setup of the SPCS consists of the hot dilution chamber and thermal conditioning via the evaporation unit followed by cold dilution and particle counting. The first dilution chamber preheats and dilutes the emissions while the evaporation tube is used to condition the exhaust gases. The second dilution chamber cools the emission gases while the particle counter counts the amount of particulates in the emissions.

AVL-I60 SESAM, Exhaust Gas Emissions Measurements

The *AVL AMA I60* is a multi gaseous emission measurement device. The device utilizes two spectrometers, an *Antaris IGS* and a *2030HY*. The device can measure the following emissions: NO, NO_2, N_2O, NH_3O, CO, CO_2, CH_4 as well as alcohols and aldehydes. The device utilizes the Flame Ionization Detector (FID) measurement method for hydrocarbon concentrations, Non-Dispersive Infrared Detector (NDIR) for CO concentrations and Paramagnetic Detector analyzer (PMD) for O_2 concentrations. There is a wide variate of applications for the I60 within testing, since the I60 can be used for both gasoline, diesel and alcohol emissions for chassis, light/heavy duty and off-road and marine applications.

Horiba-Mexa 7000-Series Exhaust Gas Emissions Measurements

The *Horiba MEXA 7000-Series* are gaseous emissions measurement devices [32]. The MEXA 7000 can measure a wide variaty of gasses ranging from THC, CO, CO_2, O_2, NO/NO_x, N_2O, SO_2 and CH_4. The emissions can be measured from both gasoline, diesel and alcohol fuels. The MEXA device utilizes the Non-Dispersive Infrared Detector (NDIR) measurement method for CO, CO_2, HC, N_2O, NO, SO_2 as well as SF_6 emissions and the Chemiluminescence Detector (CLD) for NO_x, CH_4 and Paramagnetic Detector analyzer (PMD) for O_2 emissions. The MEXA unit can be used for measurement for both chassis, light/heavy duty, as well as non-road and marine applications.

6.1.2 Conditioning Systems

The conditioning equipments consisted of different units that prepare the fuel and air to the engine and test cell.

AVL-753c, Fuel Temperature Control

To achieve a high level of precision within a test cell it is required to control the supplied fuel to a constant temperature[33]. To achieve this, the *AVL-364c Fuel Temperature Control* can be used. The *AVL-364c* is a fuel temperature control unit. The unit can deliver fuel temperatures from $10 to 80°C$. The device can also separate gas bubbles from the fuel for problem free operation. A warning system is installed that monitors the fuel for gas bubbles and outputs a warning if there are any in the fuel. This equipment can be combined together with the *AVL-735s Fuel Mass Flow Meter* to create a combined fuel measurement and conditioning unit.

6.1.3 Measurement Systems

The measurement equipment consisted of different units to measure and evaluate different aspects of an object in an engine test cell.

AVL-735s, Fuel Mass Flow Meter

The *AVL-735s Fuel Mass Flow Meter* is a fuel measurement unit that can measure up to $145kg/h$ of fuel[35]. The unit has an extension for methanol and bio fuels called "FlexFuel". The *AVL-735s* uses the gravimetric method to measure the amount of fuel that is consumed in the test cell. This equipment can be combined together with the *AVL-753c Fuel Temperature Control* to create a combined fuel measurement and conditioning unit.

AVL-740, FuelExact

The *AVL-740 FuelExact* is an fuel measurement device that can measure the consumed fuel for engines ranging up to 2500kW. The device measures the fuel via either a PLU or a mass flow technique and is thus able to measure both gasoline, diesel and bio-gases[34]. The PLU measurement principle consist of a gear-meter that feed back a geometric volume to pulse frequency ratio. This ratio is used to measure the amount of fuel that passes through the device. The PLU also has a bypass to achieve zero pressure difference, to prevent leakage flows. The mass flow measurement principle consist of a U-tube into which the fuel is fed. The tube vibrates with its natural frequency, which is proportional to the density of the fuel. The time lag is measured for the fuel as it passes through the tube. The time lag is proportional to the mass flow, which is used together with the density to calculate the volume flow.

AVL-364c, Angle Encoder

The *AVL-364c Angle Encoder* is a high precision sensor for measurements of angle speeds[36]. The sensors utilizes the reflection light principle to measure the speed of the rotating shaft and has a resolution of 720 pulses per revolution. The speed of the shaft is transmitted from the encoder via optical cables to emitter-receiver-electronics which interpret the encoders signal.

6.1.4 Utility Systems

AVL-622, Indimodul

The *AVL-622 Indimodul* is a utility connection point used in test beds. The equipment has a variaty of inputs and outputs that can handle digital and analog signals[37]. The signals are relayed to the automation system for further analysis and storage.

7 Comparison

This section covers the comparison and analysis of the two case studies, case A from Section [4] and case B from Section [5]. First, the two companies are compared generally, secondly a comparison of the differences in test's and equipment. Lastly, the maintenance and service routines are compared. At the end, each highlighted area is presented in a table that shows the implications of the differences between the case studies.

7.1 Company Comparison

Both companies were active in the same industrial area namely the automotive industry. The companies had thus similar demands on their production and facilities. The demands came from organizations and regulations that direct companies to work in a more sustainable way. Both companies had their production sites located in Sweden, which means that the companies are guided by Swedish and European laws and regulations regarding the work environment and facilities. The products that the two companies was producing/testing were however sold all around the globe, which meant that each product had to satisfy the regulations in that region of the world.

The companies conducted similar types of test, the main difference was however that Company A worked with light duty vehicles while Company B worked with both light and heavy duty vehicles. The two companies had thus different legislation limits to fulfill. Since there are different emission limits for light and heavy duty vehicles, see Appendix [C] for emission legislations for light duty vehicles and see Appendix [D] for heavy duty vehicles. The same type of management structure was however required independently of what type of tests that was conducted.

Company A with its own vehicle production had defined development objectives for each test cell. This ensured that each cell performed the same kind of test over and over again. Thus, there was no need to change the setup of equipment between each test. Company B's cells required the possibility to be able to change the setup of the cells, since the customers who ordered tests from company B, could order different tests to be conducted. This required that the TCEs and TCRs had to be fast and had to have the capability to change their cells according to the customers requests.

7.2 Testing and Equipment Comparison

The two companies were both conducting engine tests. The tests that were conducted were mainly *Dynamical* and *Functional* tests for both companies. This requires the same kind of equipment for both companies, even though the companies were working with light and heavy duty vehicles respectively, see tables [4.1], [4.2] and [5.1], [5.2]. This was due to the fact that for both types of vehicles, light and heavy duty vehicles require the same type of measurements. Emissions, consumed fuel and power produced are all measured for light and heavy duty vehicles. Company B did however have mobile devices that were used to quickly replace the ordinary equipment during maintenance, to minimize the amount of time spent waiting for equipment that was unavailable due to maintenance.

7.3 Maintenance and Service

What distinguished the companies most was the structure of the tests and maintenance. The structure of the two case studies are shown in Figure [7.1]. The development part of testing has been removed due to the fact that both companies had similar development structures.

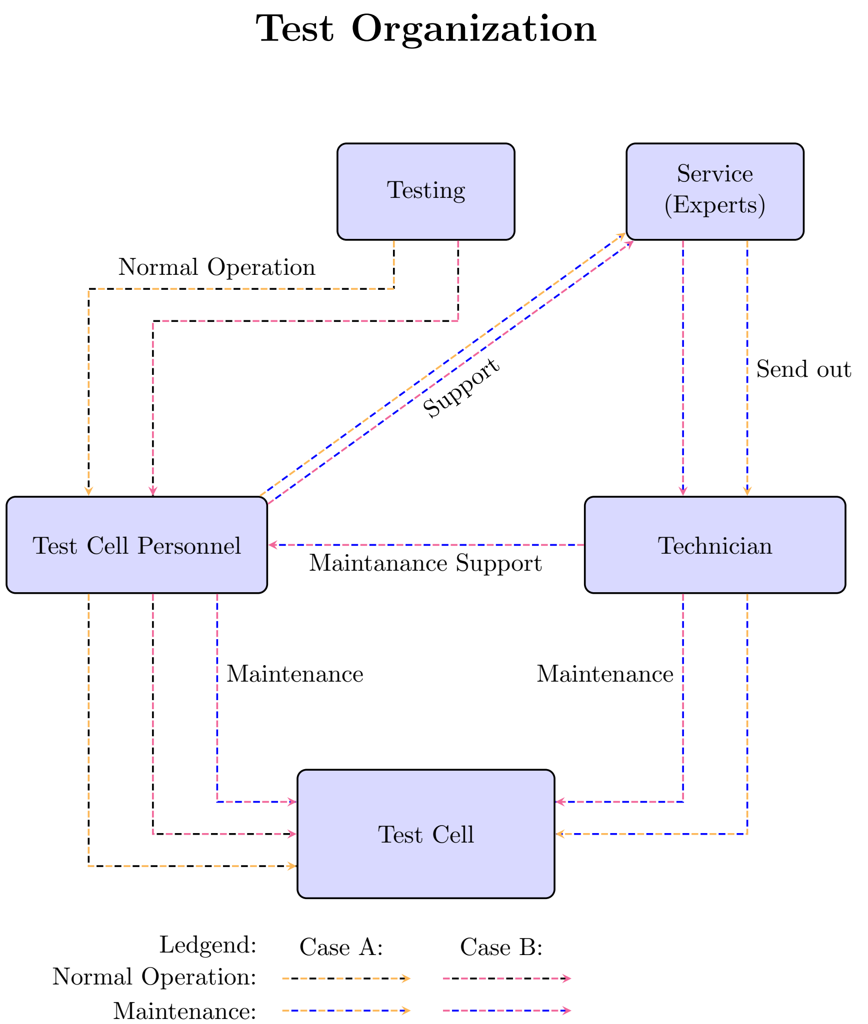


Figure 7.1: Overview of the test structure from both case studies

Company A had distributed the greatest part of the maintenance to the service and maintenance personnel. Company A had planned periods for maintenance and calibration for there cells. This meant that the cell was shut down during that period and maintenance and calibration was conducted on every device and equipment in the cell. Company B however had moved some of the responsibility of the maintenance to the TCEs and TCRs, so the service personnel worked more as a support department which could be called in to assist during larger maintenance and calibrations. Company B also had more flexible maintenance of the devices and equipment. Maintenance was performed when a device outputted a service message around 100 hours before the maximum operation time was reached. The maintenance and calibration of the cells and devices was planned so that it disturbed the tests the least.

A difference between companies A and B could been seen in the instructions for the cell operators. The instructions for company A's operators were to contact the service department whenever some equipment was malfunctioning. This resulted in that the operators filled in an error-report in the in-house computer program. The service department received the error-report and contacted the corresponding department. The operators then had to wait until the technician were in place to fix the malfunction. The operators could, if they wanted, investigate the malfunctioning equipment by themselves, but in the majority of the cases was this not done[17]. If an incorrect or an insufficient error-report had been sent via the program, then that could result in that the service department sent out the wrong technician, resulting in that the technician had to turn back and contact the correct maintenance department. The computer program at company A had an in-built function to summarize statistics over production time and downtime of the cells. The computer program could show statistics over all the cells, this helped to archive an overview of all the cells. The statistics were often used to find the correlation between low production time and malfunctions.

The operators at company B however had more responsibility regarding the maintenance and malfunctions of equipment. The TCE had the instruction to investigate and try to solve the malfunction themselves before contacting the service department. If the TCEs and TCRs were not able to solve the malfunction then an error-report was filled in the online excel sheet and the service department sent a technician to assist in the maintenance. This resulted in that the TCEs and TCRs achieved a greater understanding of the equipment. With the a greater understanding, malfunctions were solved quicker and easier each time. After a malfunction was resolved, then the excel sheet was updated with the solution to the malfunction. Over the years, a database had been created from the excel sheets, containing every deviation and the solution. The excel sheet was also used to summarize statistics for the equipment and cells. The statistics from the excel sheet showed production time and downtime for each cell. It was also used to aid the TCR to motivate purchases of new equipment.

Another difference between company A and B was their different ways to handle the error-reports. Company A had a computer program which was used to organize and contact the right department in the event of a malfunction. When a report had been filled in into the computer program then the operators had no idea when the service technician would arrive. This resulted in many cases that they often did other things during the time they had to wait for the technician. The computer program also had no function to show who was responsible for any deviation. The program only showed which department that had been contacted by the service team. Company B's error-report handling consisted of an online excel sheet were the operators filled in each deviation. The operators then either had to solve the malfunction themselves or contact the service department if they were not able to.

Highlights In Table [7.1], different areas are highlighted. Each area shows how each case study solved or performed each highlight, followed by an implication of the methods used.

Table 7.1: Highlights from the comparison

Highlight:		Case A:	Case B:	Implication:
1.	Active area:	Automotive	Automotive	None
2.	Vehicle types:	Light duty	Light and heavy duty	Case B required more extensive test cells and some equipment which was more suitable for heavy duty testing.
3.	Development objectives:	Defined	Flexible	Case A's test cells had defined development objectives which meant that no changes were required between tests. Case B had varying development objectives which required more from the operators.
4.	Equipment:	Tables: [4.1] & [4.2]	Tables: [5.1] & [5.2]	No major implication. Case B had some equipment that was more suitable for heavy duty testing.
5.	Maintenance:	Planned	Planned and Flexible	Case B's operators were more involved in the maintenance.
6.	First responsibility:	Service Department	Cell operators	Case B's operators were instructed to investigate a malfunction before contacting the service department.
7.	Report handling:	In-house Computer program	Online Excel sheet	The different report methods were used for different applications.
8.	Production statistics:	Detailed overview over all the cells	Overview of the time spent for each deviation	The statistics were used for different purposes

8 Synthesis

In Table [7.1], in Section [7], it was shown that the two case studies had some differences and similarities in each of the highlighted areas. The highlights showed that each case study had different methods to solve the common tasks, to perform tests and maintaining the equipment. From the table different improvement opportunities emerge, presented in Section [8.1]. From the improvement opportunists different functions were created. The functions are summarized in a functions table, Section [8.2], where each function has a desired property correlated to an improvement opportunity. An improvement concept is presented in Section [8.3].

8.1 Improvement opportunities

From Table [7.1] the differences and similarities were numbered from 1 to 8 to distinguish the highlights from each other. From the comparison table each aspect was also labeled with an implication and from the implications emerged different improvement opportunities. In Table [8.1] each implication is listed, followed by a correlated improvement opportunity. Each improvement is labeled with an effect that the improvement could have. The table contains only highlights where the two case studies have different methods to solve or to perform the same action. These highlights were [5, 6, 7, 8], see Table [7.1].

Table 8.1: Improvement Opportunities

Highlight:		Case study:	Improvement opportunity:	Implication:
5.	Maintenance:	A	Make sure that the operators are involved in the maintenance.	By performing or participating in the maintenance the operators will achieve a greater understanding of the cell and equipment. **Increased Reliability**[51]
6.	First responsibility:	A	Move some of the responsibility to the operators instead of the service department.	If the operators do a first check of the malfunction, then the operators can do an initial assessment and contact the responsible service department directly. **Decreased intermediate steps**[3] **Decreased Mean Wait Time (MWT)**[52]
7.	Report handling:	A	Communication	When an operator sends a report, the service department should be able to answer the operator's report immediately. To avoid that the operators leaves the cell and perform unnecessary work. **Increased Productivity**[53&54]
7.	-	A	Responsibility indication	If the operators directly see which service department that is responsible for a certain malfunction, the operators may be able to contact the right department and technician directly, which will decrease the amount of intermediate steps between report and solution to a malfunction. **Increased Productivity**[3] **Decreased Mean Time To Repair (MTTR)**[53]

Highlight:		Case study:	Improvement opportunity:	Implication:
7.	-	B	Proper software for malfunction reporting	The current system meant that reports could be forgotten to be sent, due to that the operators had to enter the report into the excel sheet by themselves. By using a more advanced system the chance that the operator forget to send reports decreases. then more reports can be received by the service department, and production can continue faster after a malfunction. **Improved productivity**[3]
8.	Production statistics:	A	Current system had a good overview over statistics, while the information was not fully available for the operators.	The operators had to switch computers to be able to see the statistics. By allowing the operators to see the statistics over the cell directly from computers in the cell a further understanding of down-time and cost can be achieved. **Improve troubleshooting**[3]
8.	-	B	Current system showed only the down-time correlated to each malfunction.	By increasing the amount of information which could have been shown, the operators can understand the importance of maintenance. **Improve troubleshooting**[3]

A sub-goal of the project was to investigate improvements which could be beneficial to both companies. Hence, it was chosen together with the supervisors from AVL, that a improvement opportunity had to be connected with the automation system, rather than suggesting changes to the work structure. The following work was limited to an automation improvement. This implies that improvements opportunities [5 and 6] regarding the responsibility and maintenance of the operators were not further investigated.

8.2 Function Table

As presented in the case studies as well as in the comparison, both case studies had separate computers that were used to fill in reports. An addition to the automation system would be to handle error reports directly in the interface, rather then having separate computers.

An important property of an improvement would be that is should have an “easy to use” interface[3] and would not require more time from the operators then before. An improvement was supposed to increase the overall efficiency and lower the amount of time lost due to unnecessary actions. A function table was created from the highlights in Table [7.1] together with the improvement opportunities from Table [8.1]. The table was divided in three main functions with different properties correlated to the functions. The table was extended to show if every function was either required or wanted, by labeling each property with an R for Required and W for Wanted.

Table 8.2: Function table (R=Required function, W=Wanted Function)

Functions:	Properties:	Required / Wanted:	Comment:
Main functions:	Inbuilt in Automation system	R	Reporting of malfunctions from the automation system directly.
-	Handle malfunctions from all manufacturers	R	-
-	Collect “Log-files”	R	For troubleshooting
-	Simple layout	W	Not time consuming
Direct communication with:	Service department	R	-
-	External service	W	For further support, the report could be sent to the manufacturers service department.
Show:	Responsibility of malfunctions	R	-
-	Statistics.	W	Show statistics directly on screen in the automation system's interface
-	Current and old malfunctions.	W	To enable the option to search for solutions in older reports.

8.3 Integrated report concept

From Table [8.2], a concept for a report system was created. The system was supposed to be integrated into the interface of any automation system. The functions of the error report concept can be found in the following pages with figures correlated to the descriptions.

8.3.1 Reporting

The concept had two windows with one identification panel above, see Figure [8.1]. The identification panel showed the identification of the cell and the identification number of the current report. The two windows: *Select* and *Message*, had different purposes. The *Message* window (right window in Figure [8.1]) was used to enter information and to send the reports to the service departments, while the *Select* window (left window in Figure [8.1]) was used to select which part/parts of the cell that was malfunctioning.

The *Select* window had five buttons that had different purposes. The first four buttons *Facility*, *Object*, *Equipment* and *Other*, was used to select which part/parts that were malfunctioning, while The last button in the *select* window, the *Status* button, was used to show statistics over the cell and current reports, a more through description of this part can be found in Section [8.3.2]. The *Message* window changed layout when one of the first four buttons were selected. For instance if the *Equipment* button was selected then the *Message* window changed to show all the available equipment for that specific cell, see Figure [8.3.1] for a visual representation of this. Similarly would the *Message* window change and show different list containing all the associated apparatus and utilities for the specific cell if any of the other three buttons were selected. When the operator had finished selecting all the parts that were not functioning as supposed to, the operator could return to the original message window either by the close down cross-mark in the top right or by de-selecting the button in the *Select* window.

When the operators had selected the malfunction part/parts from the *Select* window, then operator had to enter information regarding the malfunction in the text box in the *Message* window. When the operator was finished, then the operator either had to send the report to the in-house service department and/or to the external service departments by selecting between the two buttons *In-House* and *External.* The *In-House* button was used for the in-house service department and the *External* button was used for the external service departments. The operator then signed the report by entering his/her ID and pushing the *Send* button to send the report.

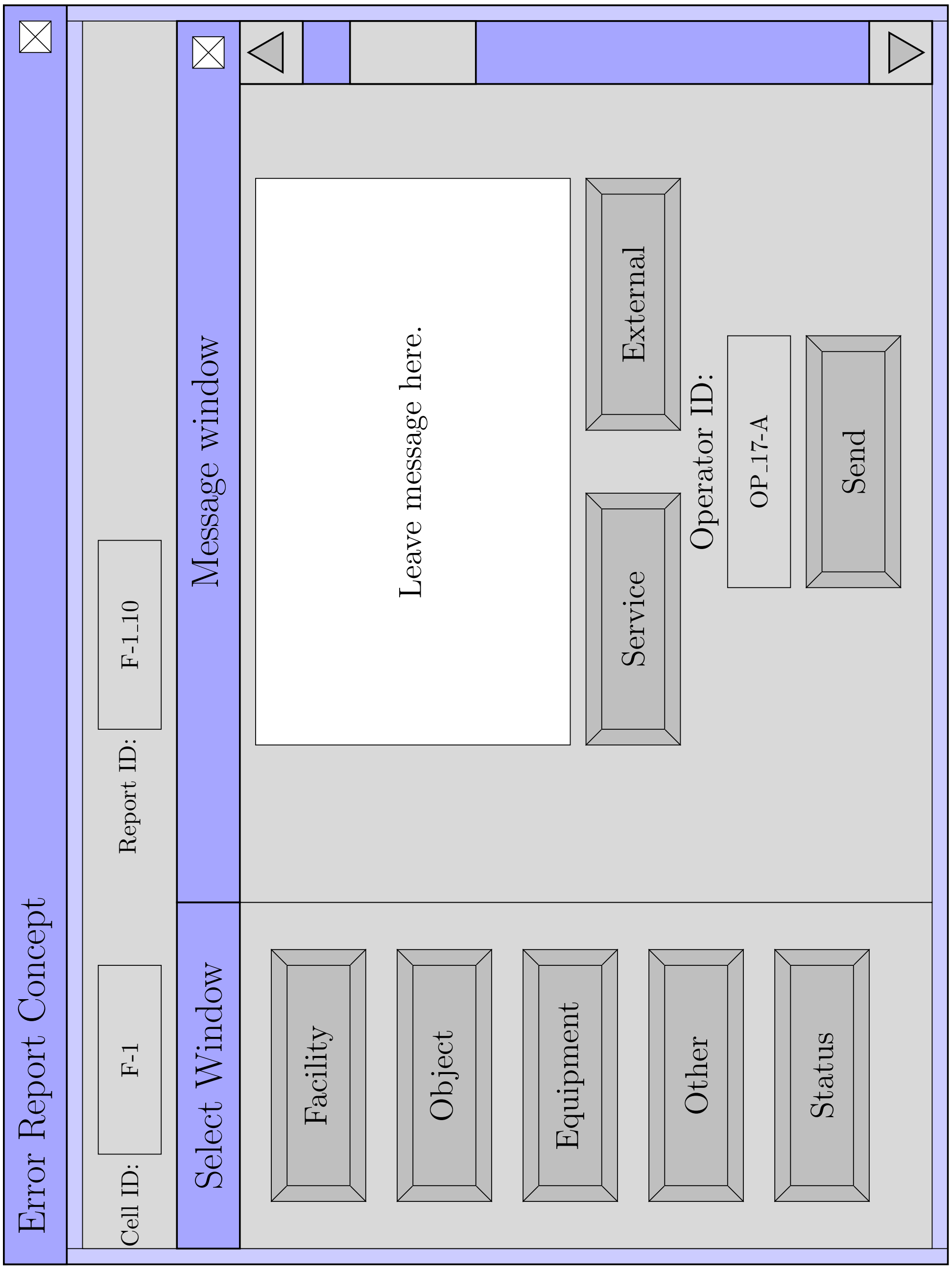


Figure 8.1: Overview of the integrated report concept

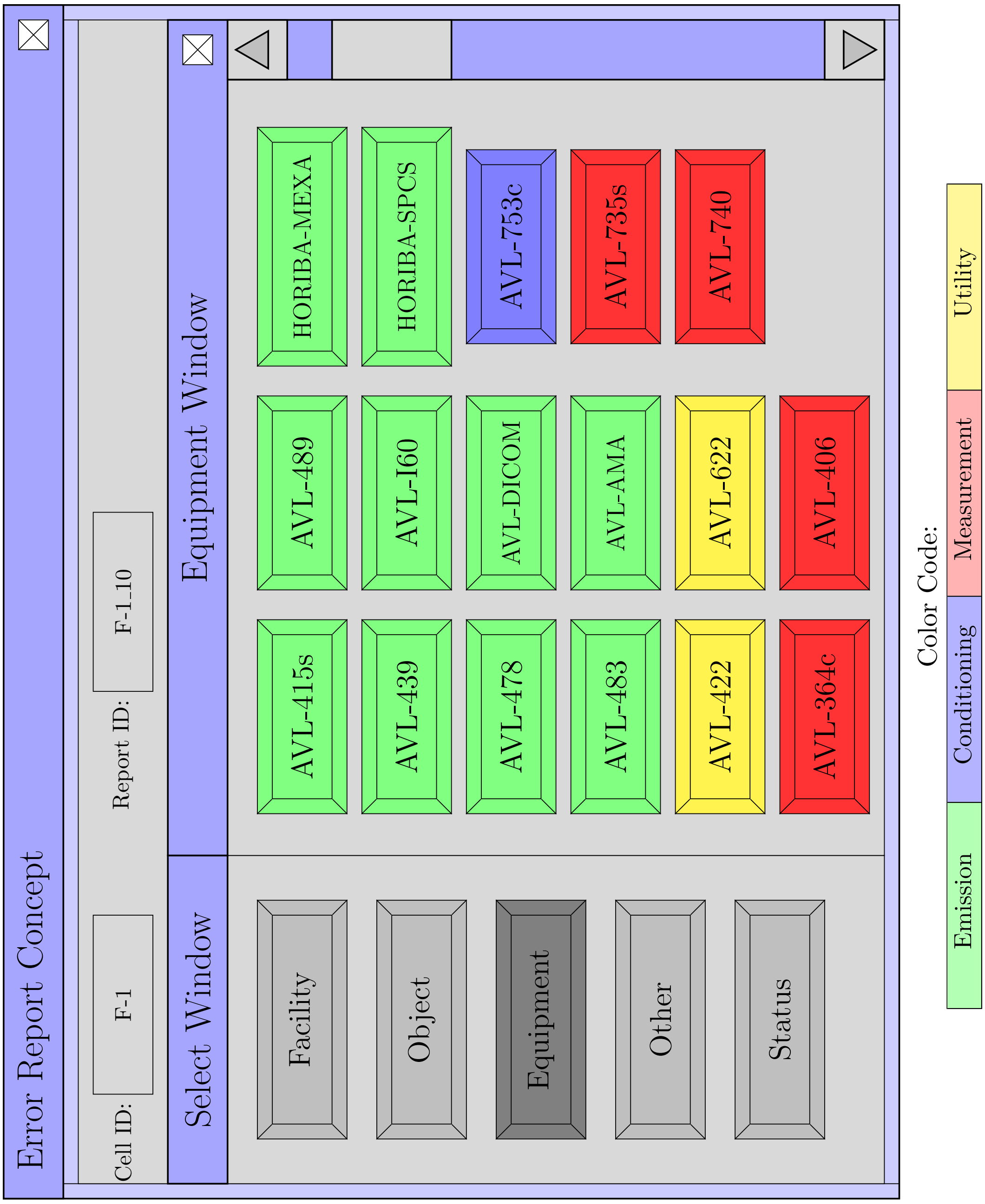


Figure 8.2: Integrated report concept: Equipment

8.3.2 Status

The fifth and furthest down button in the *Select* window, the *Status* button was used to show statistics of the cell. When the operator selected the *Status* button, then the two windows, *Select* and *Message* changed to show the statistics of the cell, the amount of downtime and the correlated reports and malfunctions. The *Select* window was changed to *Status* window with two new buttons. The two new buttons were: *Statistics* and *Reports*. By selecting one of the two, the *Message* window change to show the corresponding window.

The *Statistics* button was used to show graphs over the amount of malfunctions during each week and the corresponding time loss due to the malfunctions, see Figure[8.3], while the *Reports* button was used to show each report that was associated to the cell, with the report ID, the responsibility of the malfunction, which part of the cell that was malfunctioning, status of the report and the time loss. This can be seen in Figure [8.4]. The *Reports* button was used to investigate the correlation between down-time of the cell and the malfunctioning of certain parts of the cell. The operator could close the *Status* window either by the close down cross-mark in the top right or by de-selecting the *Select* button.

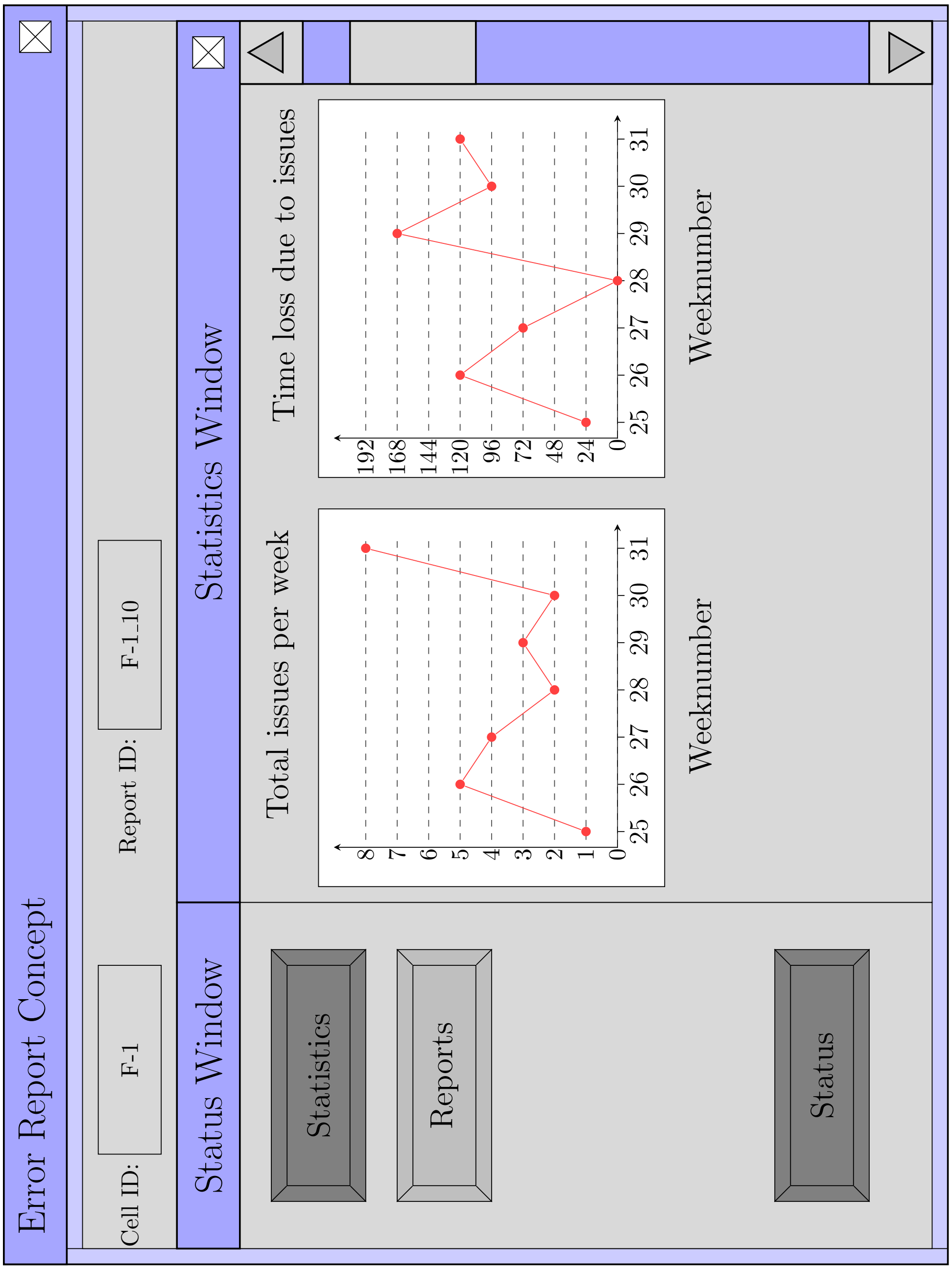
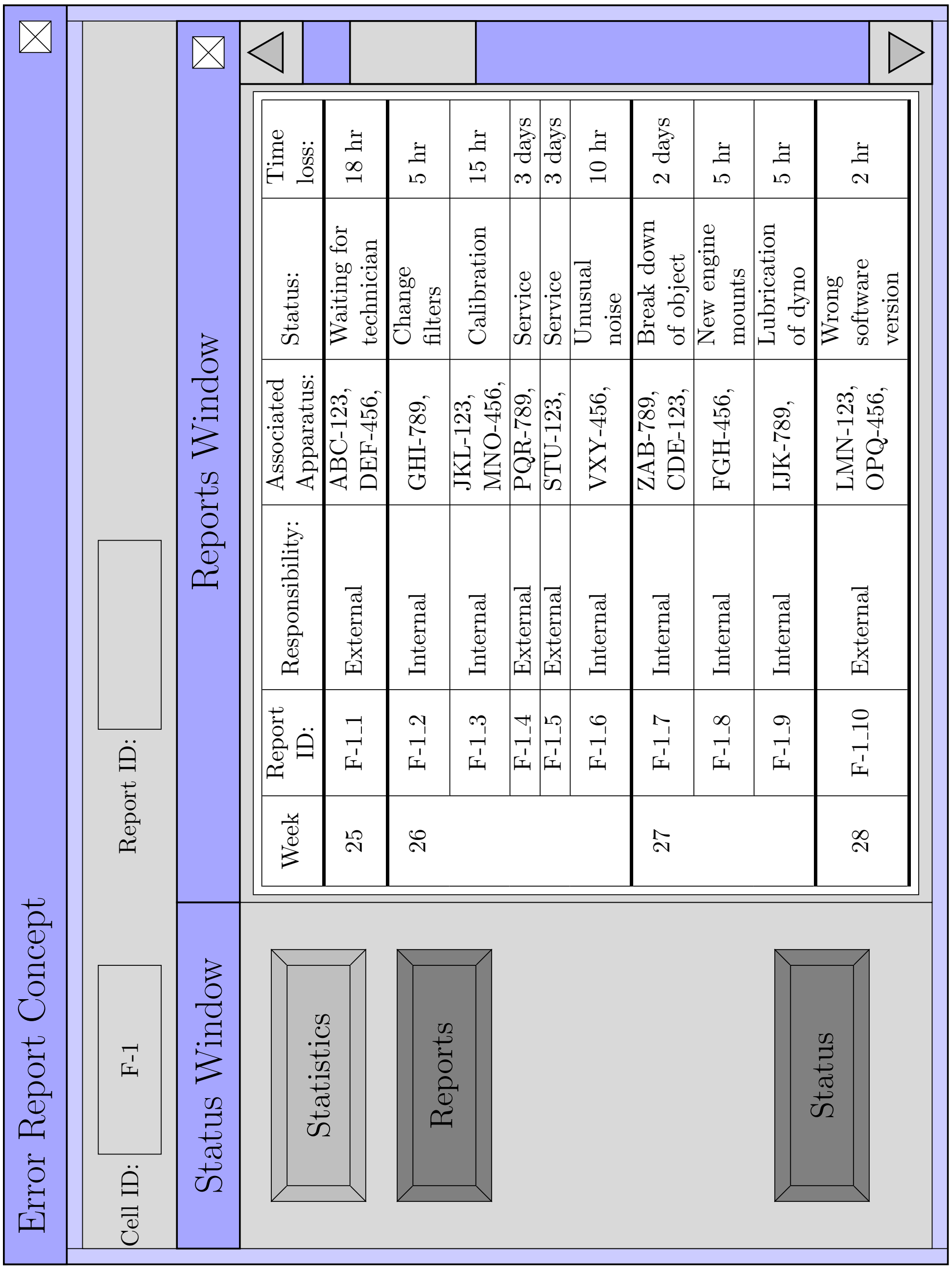


Figure 8.3: Integrated report concept: Status - Statistics Window



Week	Report ID:	Responsibility:	Associated Apparatus:	Status:	Time loss:
25	F-1_1	External	ABC-123, DEF-456,	Waiting for technician	18 hr
26	F-1_2	Internal	GHI-789,	Change filters	5 hr
	F-1_3	Internal	JKL-123, MNO-456,	Calibration	15 hr
	F-1_4	External	PQR-789,	Service	3 days
	F-1_5	External	STU-123,	Service	3 days
	F-1_6	Internal	VXY-456,	Unusual noise	10 hr
27	F-1_7	Internal	ZAB-789, CDE-123,	Break down of object	2 days
	F-1_8	Internal	FGH-456,	New engine mounts	5 hr
	F-1_9	Internal	IJK-789,	Lubrication of dyno	5 hr
28	F-1_10	External	LMN-123, OPQ-456,	Wrong software version	2 hr

Figure 8.4: Integrated report concept: Status - Reports Window

9 Discussion

This section discusses the data collection from the case studies and the analysis of the data. Furthermore, the concept model is discussed together with future improvements.

9.1 Data collection

The data from the case studies was collected together with representatives from both companies. The representatives from both company A and B had been suggested from the supervisors from AVL and the maintenance management at both companies. The data collected from the interviews with the representatives may have resulted in that the concept model may only be beneficial for these companies. Since other companies may have different maintenance structures where the concept does not fit into the daily work. Due to time limitation it was not possible to include another company to extend the review.

The investigator wrote notes during the each interview with the representatives from the companies. During the interviews the researcher may have misinterpreted some of the information discussed, which in the end may have resulted in that the descriptions of the companies and their structure is not exactly as the real structure of the companies. The representative may also deliberately have passed on data that incorrectly describe the company and the organization.

The comparison and analysis was performed by the researcher. Thus, the highlights that are presented in table [**??**] at the end of the section [7] is only influenced by the researcher alone.

The function list consisted of areas that the investigator felt was important to increase production and utilization for the two companies. The concept model however, does not consider whether or not the companies are willing to use the automation system for reporting malfunctions. The companies may prefer the current methods for reporting malfunctions. An implementation of a report system in the automation system might seem unnecessary and superfluous for the two case studies and other companies.

9.2 The integrated report concept

As stated before, the integrated report concept is based on the analysis by the researcher. Applications which might be suitable for an error report system may not be interested in the system, since the highlight that is presented might not be of any concern for those applications.

The concept is designed to be simple and provide an overview of the cell's status. This may be regarded as too much information available. The statistics portion may be modified to perhaps show other statistics than those presented as an example in the report.

Vehicle and engine testing is a high technological area that is very sensitive to information leakage. Thus, companies might be cautious of a system that can transfer information, due to risks of leakage of sensitive information.

Each automation system has different layouts. The presented concept might not fit into the layouts of every automation system available. Therefore different versions of the layout of the concept should be available to allow customization for each automation system. This will however require another study which focuses on what automation systems that is commonly used and for what purposes. The concept can then be customized to fit more applications.

The report concept can be used to increase the operators responsibility towards the cell. If the operator is more involved in the investigations of statistics, this can motivate them to work more towards increasing the operation time of the cell, while in the mean time striving to have as low amount of malfunctions as possible.

9.3 Further development

In the event of a malfunction that is new for a specific test cell, the report concept could be expanded to search its database for older reports, or for reports from other cells, in order to suggest a solution. This could also be used to search for recurring malfunctions across different cells.

The concept could also be expanded to display the statistics of all the cells at the companies facilities, in order to show how the cell performed compared to the other cells. If there is a large variation between the cells, then there might be a bottle neck in the production.

Another development option could be to include a calender for scheduling of service and calibration. In the two case studies, this was done by an external calender outside of the automation system. In addition to this, the operation time of the equipment and facilities could be shown in the automation system, to be able to schedule tests and services at the most adequate time frame.

10 Conclusion

The conclusion section aims to answer the goals of the project, which are found in the introduction section, see Section [1].

How can the automation system be utilized to increase the total throughput?
The automation system is connected to every part and equipment of the test cell and is thus a vital part of the cell. From the case studies it was found that the automation system could be used for more than its current functions. By expanding the automation system to be able to send reports directly from the interface, the amount of intermediate steps for sending a report can be decreased. The option to send reports from the automation system ensures that the operators do not have to go to another separate computer to send the reports. Also, if the operators are able to communicate with the service personnel some tasks may be solved without involving a technician. Since the operators may be able to solve some malfunctions by themselves with the guidance of the service personnel, this would result in that malfunctions can be solved quicker and that the operators will achieve a greater understanding of the cell and the equipment. Furthermore, this can have a positive effect on the production time, since less time is spent on unnecessary work, thus increasing the total throughput.

How was the maintenance structure of the two case studies?
The maintenance structure of the two case studies can be seen in the two figures [10.1] and [10.2]. The first figure describes how the testing and maintenance structure was for case study A, while the second figure shows how the testing and maintenance structure was for case study B.

For case study A, the majority of the maintenance was performed by the service personnel, while the operators did some minor daily maintenance consisting of changing filter and purging of emissions equipment.

For case study B however, the operators were more involved in the maintenance. The operators were instructed to investigate and try to solve a malfunction before contacting the service department. If the operators were not able to solve the malfunction, then the service department acted as support and instructed and guided the operators while they performed the maintenance. If the operators still were not able to solve the malfunction, then the service department took over the responsibility of the malfunction while the operators participated in the malfunction.

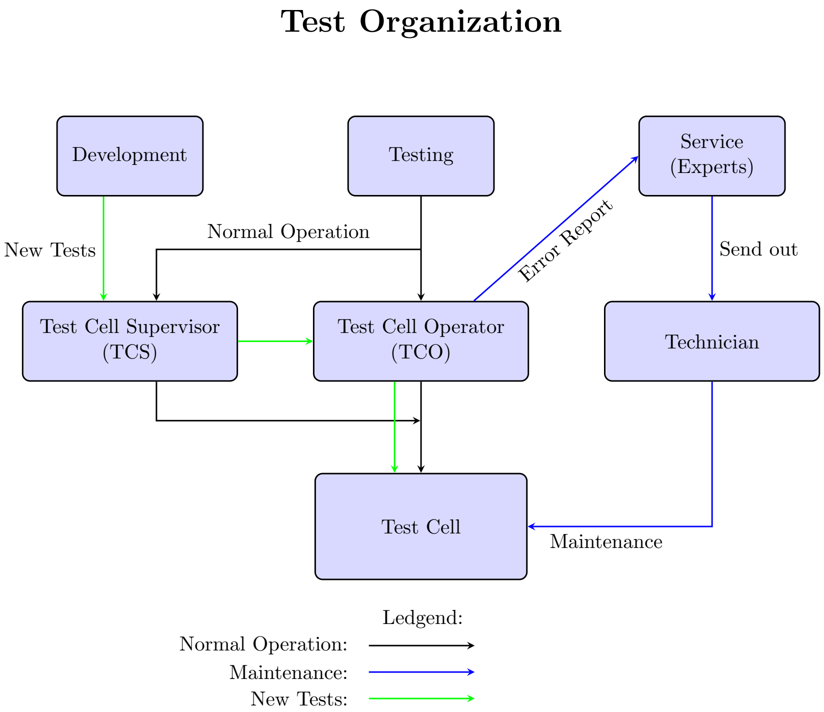


Figure 10.1: Case A: Structure

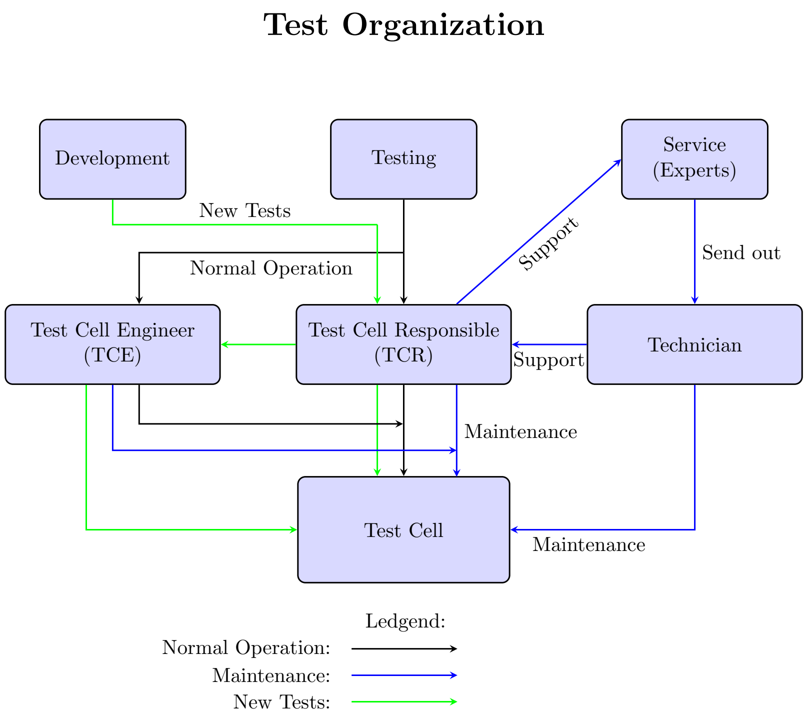


Figure 10.2: Case B: Structure

What were the main differences in the two companies structure.
The main difference between the two case studies was the instructions and how much responsibility the cell operators had. Company A's operators were instructed to only perform simpler maintenance tasks such as changing filters on certain equipments, while in the mean time only having the responsibility of current test. Company B's operators had more responsibility regarding the maintenance of the cell, which enabled them to participate and perform more advanced maintenance. Thus did the operators at case study B achieve more knowledge regarding the cell and the equipment within it by performing maintenance.

The comparison of the structure for the two case studies can be seen in Figure [10.3], as well as in Section [7]. The development part is not included in the figure since both companies had similar development structure. As seen in the figure, company B's operators are more involved in the maintenance and are instructed to investigate and try to solve a malfunction before contacting the service department. If the service department was contacted, then the first action was to assist the operators in solving the malfunction and then solve it with the operators help.

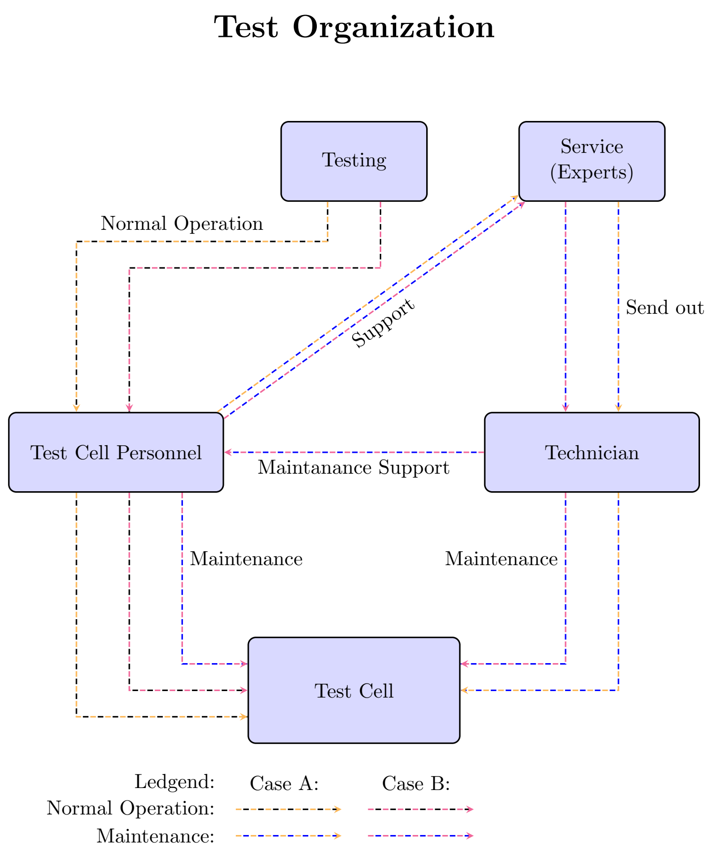


Figure 10.3: Overview of the test structure from both case studies

What automation improvement could be beneficial for both companies?
As presented in Table [7.1], the two case studies had similarities and differences within different aspects. From the table it was decided that an improvement should make it easier for the operator in some aspects while in the mean time increase the efficiency for the operators.

The highlights in the table which could be connected to an improvement for both companies, while being connected towards the automation system, was highlights regarding *Maintenance*, *Responsibility*, *Report Handling* and *Production statistics*. These four aspects are closely connected to minimizing the amount of down-time, increasing the efficiency while finding the correlation between the down-time and malfunctioning equipment.

Will the overall efficiency and utilization at test cells be increased?
With an integrated report system implemented, the operators can send reports and receive answers quicker from the service department. This will decrease the amount of nonproductive intermediate steps for the operators. In the mean time, the service department can establish a dialog with the operators, thus asking leading questions that can narrow down the malfunction to one specific part, which in the end will allow the service department to send out a technician with the required knowledge and experience to solve the malfunction.

How can other similar installations benefit of this implementation?
Automation systems of this kind are used in a lot of different applications. This thesis has been limited to dynamical and functional engine testing, but there are a variety of different fields where a system like this can be utilized to simplify the work for both the operators and service personnel.

However, it is important to note that the concept that has been presented may not be suitable for all applications. Some modifications may be needed to make the system fit other applications.

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Appendices

Appendix A Interview Template

Case Study:		Date:
Representative:		Position:
Contacted via:		
Questions:		Answer:
1.	How are you connected with the daily work with the test cells? *- What are your responsibilities?*	*Aims to get a general understanding of the representatives background and expertise.*
2.	How are you connected to the maintenance? *- What are your responsibilities?*	*Aims to understand how the responsibility were divided in the case study.*
3.	What would be your first action in the event of and malfunctions *- Would you investigate the malfunction and try to solve it?* *- Would you contact anyone else?*	*Aims to understand how the case study worked with maintenance* *Aims to further investigate the responsibility and deviation instructions.*
4.	How do you report deviations?	*Aims to understand the flow of reports.*
5.	How is statistics shown? *- How would you access it?*	*Aims to understand how statistics was used in the case study.*
6.	Any other subjects which might be interesting to investigate?	*Aims to allow the representative to express their own thoughts and ideas which might lead to development potentials.*

Appendix B EURO 5a

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ANNEX I

EMISSION LIMITS

Table 1

Euro 5 emission limits

			Limit values													
		Reference mass (RM) (kg)	Mass of carbon monoxide (CO)		Mass of total hydrocarbons (THC)		Mass of non-methane hydrocarbons (NMHC)		Mass of oxides of nitrogen (NO_x)		Combined mass of total hydrocarbons and oxides of nitrogen (THC + NO_x)		Mass of particulate matter (PM)		Number of particles [1] (P)	
			L_1 (mg/km)		L_2 (mg/km)		L_3 (mg/km)		L_4 (mg/km)		$L_2 + L_4$ (mg/km)		L_5 (mg/km)		L_6 (#/km)	
Category	Class		PI	CI	PI	CI	PI	CI	PI	CI	PI	CI	PI [2]	CI	PI	CI
M	—	All	1 000	500	100	—	68	—	60	180	—	230	5,0	5,0		
N_1	I	RM ≤ 1 305	1 000	500	100	—	68	—	60	180	—	230	5,0	5,0		
	II	1 305 < RM ≤ 1 760	1 810	630	130	—	90	—	75	235	—	295	5,0	5,0		
	III	1 760 < RM	2 270	740	160	—	108	—	82	280	—	350	5,0	5,0		
N_2			2 270	740	160	—	108	—	82	280	—	350	5,0	5,0		

Key: PI = Positive ignition, CI = Compression ignition

(1) A number standard is to be defined as soon as possible and at the latest upon entry into force of Euro 6.

(2) Positive ignition particulate mass standards apply only to vehicles with direct injection engines.

Appendix C EURO 5b & 6

L 199/130 EN Official Journal of the European Union 28.7.2008

Table 1

Euro 5 Emission Limits

			Limit values													
		Reference mass (RM) (kg)	Mass of carbon monoxide (CO)		Mass of total hydrocarbons (THC)		Mass of non-methane hydrocarbons (NMHC)		Mass of oxides of nitrogen (NO_x)		Combined mass of hydrocarbons and oxides of nitrogen (THC + NO_x)		Mass of particulate matter (¹) (PM)		Number of particles (²) (P)	
			L_1 (mg/km)		L_2 (mg/km)		L_3 (mg/km)		L_4 (mg/km)		$L_2 + L_4$ (mg/km)		L_5 (mg/km)		L_6 (#/km)	
Category	Class		PI	CI	PI	CI	PI	CI	PI	CI	PI	CI	PI (³)	CI	PI	CI
M	—	All	1 000	500	100	—	68	—	60	180	—	230	5,0/4,5	5,0/4,5	—	6,0 x 10^{11}
N_1	I	RM ≤ 1 305	1 000	500	100	—	68	—	60	180	—	230	5,0/4,5	5,0/4,5	—	6,0 × 10^{11}
	II	1 305 < RM ≤ 1 760	1 810	630	130	—	90	—	75	235	—	295	5,0/4,5	5,0/4,5	—	6,0 × 10^{11}
	III	1 760 < RM	2 270	740	160	—	108	—	82	280	—	350	5,0/4,5	5,0/4,5	—	6,0 × 10^{11}
N_2	—	All	2 270	740	160	—	108	—	82	280	—	350	5,0/4,5	5,0/4,5	—	6,0 × 10^{11}

Key: PI = Positive Ignition, CI = Compression Ignition

(¹) A revised measurement procedure shall be introduced before the application of the 4,5 mg/km limit value.

(²) A new measurement procedure shall be introduced before the application of the limit value.

(³) Positive ignition particulate mass standards shall apply only to vehicles with direct injection engines.

Table 2

Euro 6 Emission Limits

			Limit values													
		Reference mass (RM) (kg)	Mass of carbon monoxide (CO)		Mass of total hydrocarbons (THC)		Mass of non-methane hydrocarbons (NMHC)		Mass of oxides of nitrogen (NO_x)		Combined mass of hydrocarbons and oxides of nitrogen (THC + NO_x)		Mass of particulate matter (¹) (PM)		Number of particles (²) (P)	
			L_1 (mg/km)		L_2 (mg/km)		L_3 (mg/km)		L_4 (mg/km)		$L_2 + L_4$ (mg/km)		L_5 (mg/km)		L_6 (#/km)	
Category	Class		PI	CI	PI	CI	PI	CI	PI	CI	PI	CI	PI (³)	CI	PI (⁴)	CI (⁵)
M	—	All	1 000	500	100	—	68	—	60	80	—	170	5,0/4,5	5,0/4,5		6,0 × 10^{11}
N_1	I	RM ≤ 1 305	1 000	500	100	—	68	—	60	80	—	170	5,0/4,5	5,0/4,5		6,0 × 10^{11}
	II	1 305 < RM ≤ 1 760	1 810	630	130	—	90	—	75	105	—	195	5,0/4,5	5,0/4,5		6,0 × 10^{11}
	III	1 760 < RM	2 270	740	160	—	108	—	82	125	—	215	5,0/4,5	5,0/4,5		6,0 × 10^{11}
N_2	—	All	2 270	740	160	—	108	—	82	125	—	215	5,0/4,5	5,0/4,5		6,0 × 10^{11}

Key: PI = Positive Ignition, CI = Compression Ignition

(¹) A revised measurement procedure shall be introduced before the application of the 4,5 mg/km limit value.

(²) A number standard is to be defined for this stage for positive ignition vehicles.

(³) Positive ignition particulate mass standards shall apply only to vehicles with direct injection engines.

(⁴) A number standard shall be defined before 1 September 2014.'

(⁵) A new measurement procedure shall be introduced before the application of the limit value.

Appendix D EURO VI

L 188/10 EN Official Journal of the European Union 18.7.2009

ANNEX I

Euro VI emission limits

	Limit values							
	CO (mg/kWh)	THC (mg/kWh)	NMHC (mg/kWh)	CH_4 (mg/kWh)	NO_X (1) (mg/kWh)	NH_3 (ppm)	PM mass (mg/kWh)	PM (2) number (#/kWh)
ESC (CI)	1 500	130			400	10	10	
ETC (CI)	4 000	160			400	10	10	
ETC (PI)	4 000		160	500	400	10	10	
WHSC (3)								
WHTC (3)								

Note:
PI = positive ignition.
CI = compression ignition.
(1) The admissible level of NO_2 component in the NO_x limit value may be defined at a later stage.
(2) A number standard is to be defined at a later stage and no later than 1 April 2010.
(3) The limit values relating to WHSC and WHTC, replacing the limit values relating to ESC and ETC, will be introduced, at a later stage, once correlation factors with respect to the current cycles (ESC and ETC) have been established, no later than 1 April 2010.

Appendix E Maintenance Routines

Each piece of equipment requires different maintenance actions, performed at different periods of time or operation cycles. Each action ensures that the system can operate correctly. The equipment may have different routines depending on how long the system has been running. Some systems require more or less maintenance then others. Here follows the maintenance routines of the equipment presented in Section [6.1].

E.1 Routines - Emission Systems

AVL-415s, Smokemeter

The *AVL-415s Smokemeter* have different sets of maintenance procedures depending on the unit's operating condition. The three different operating conditions are specified in the supplied operating manual[38] and are presented below. The Service Intervals of the internal components are also specified in the manual.

1. **Permanent Operation:** 24h/d - 6 to 7 days a week.
   - Service every three weeks
   - Full service or replacement of pump every three(3) months
2. **Average Use:** Each time the paper is changed, perform the following:
   - Inspect reflectormeter head, clean if necessary.
   - Inspect the two fine filters, replace if necessary.
   - Inspect the blackened filter area.
   - Perform a leak check.
   - Check white value disk for soiling and clean if necessary.
   - Lubricate moving parts.
3. **Average Use:** 300 Operating hours or 10'000 Measurements
   - Check reflectormeter head, clean if necessary.
   - Check the sampled volume.
   - Clean the sampling line tube with ultra-clean, oil- and water-clean compressed air.
   - Clean the light gate 1 with ultra-clean, oil- and water-clean compressed air.
   - Check filter mat for cooling air.
   - Check the ratchet clip and the clamping lever.
   - Replace all fine filters.
   - Clean and lubricate all moving parts.
   - Check pump noise and check nominal pump flow.

In addition to the maintenance routines mentioned above, annually maintenance is required. The extent of the annual maintenance is described in Table [E.1]. and can be found in the operating manual[38] for *AVL-415S - Smoke Meter*.

Table E.1: Maintenance Routines - AVL-415S Smoke Meter

Component / Test	Maintenance	Replacement
Leak check.	For checks of sample lines and probes: supported on SERVICE MODE only perform with sampling probe and line. Special sampling.	-
Reflectometer head.	Check and clean or replace if necessary. Adjustment if necessary and calibration.	Every two years.
Light gate 1.	Check and clean if necessary.	If damaged.
Camshaft.	Check and clean or replace if necessary.	Every two or three years or after 3000 operating hours.
Fine Filters.	Replace.	-
White value plate.	Clean the deposit on the standard.	if necessary.
Filter paper.	Check the homogeneous blackening with exactly delineated round contour.	-
Sealing ring of the suction unit.	Check there is no deposit, clean if necessary. Glue the sealing rings into the clamping device (suction unit) Check the sealing ring for defects and correct sealing ring position.	If damaged replace the sealing rings.
Clamping piece rolls, axles press fit bush bearing.	Clean and lubricate all points.	If necessary.
Sampling probe, sampling line.	Check and clean.	1000 - 2000 operating hours.
Filter mat.	Replace.	Annually.
Check sampled volume.	Check.	Replacement of the glass caliber of the volume tester is necessary when it is scratched or contaminated with dirt.
Adjustment of the transport paper mechanism.	Function check and adjustment if necessary every time spare parts are exchanged.	-
Adjustment of the slip clutch.	Check tension and adjustment if necessary	-
Ratchet clip.	Replace.	Annually.
Clamping lever.	Visual check	If damaged or if any part is bent off.

Component / Test	Maintenance	Replacement
Pump.	Check and replace if necessary.	Every 2000 - 3000 operating hours.
Nipple and hose connections.	Replace.	Annually.
Cleaning of electronic boards.	Clean with high purity compressed air.	If necessary of defective.
Check valve.	Check and replace if necessary.	Annually.
Pressure reduction assembly.	Check.	After assembly.
Pressure switch of shop air option.	Check and adjust if necessary.	Annually.

AVL-439, Opacimeter

The *AVL-439 Opacimeter* is designed to withstand long use with little maintenance. This is possible due to the internal equipment namely: the sampling conditioning, heated measurement window as well as the automatic purge function. There is one filter that requires replacement once in a while, this filter is used to filter sampling exhaust gas for particles. The opaciometer has an inbuilt function that indicates when the filter requires replacement. The operating manual[39] supplies some cleaning recommendations which is listed in Table [E.2].

Table E.2: Cleaning recommendations - AVL-439 Opaciometer

Recommendation	Instant
Changing the filter element.	When “Flow Rate Warning” is output.
Cleaning the heated window modules.	When soot residues and/or other gas components soil the window. When an error message is output during zeroing.
Cleaning the sampling lines.	When emissions peaks are visible in the measurements due to emission residues that are present in the lines.
1000 hour service.	When the message “1000 hours service” is output.

AVL-478, Smart Sampler

The maintenance of the *AVL-478 Smart Sampler* consists of maintenance for both the filter and the control cabinet, and can be seen in the following tables [E.3] and [E.4]. The maintenance is either performed by the cell operators or by trained personnel from AVL.

Table E.3: Maintenance Routines - AVL-478 Smart Sampler Control Cabinet

Part	**Local operator**			**AVL Service Engineer**			
	Daily	**Once a week**	**Once a month**	**3 months**	**6 months**	**12 months**	**After Major Service intervention (or 24 months)**
Compressed Air Filter: • Must be cleaned monthly • Replace after 2 years			●	●	●	●	● (Replace)
Clean/Replace High Efficiency Particulate Air Filter						●	
Check/Replace Diluted Sample Return Filter				●	●	●	●
Check/Replace Sensor housing fan filter				●	●	●	●
Check/Replace Electrical Panel fan filters (2x)				●	●	●	●
Automatic leak check: • Pressure • Vacuum	●						
Manual leak check: • Pressure • Vacuum			●				●
Check for leaks at interconnection - torque fittings							●
Adjust MV-CAL			●				●
Adjust Pressure Regulators: • PR-PMP • PR-DIL	●						
Sensor Calibration: • Temperature • Pressure • Voltages • Flows						●	●

Part	**Local operator**			**AVL Service Engineer**			
	Daily	**Once a week**	**Once a month**	**3 months**	**6 months**	**12 months**	**After Major Service intervention (or 24 months)**
Gp (probe) check	●						●
G_{tot} flow check		●					●
Flow Calibration		●					●
G_{DIL} Verification						●	
G_p Probe Flow Meter Verification							●

Table E.4: Maintenance Routines - AVL-478 Smart Sampler Filter Cabinet

Part	**Local operator**			**AVL Service Engineer**			
	Daily	**Once a week**	**Once a month**	**3 months**	**6 months**	**12 months**	**After Major Service intervention (or 24 months)**
Pressure Regulator PR-FIL setting:	●						
Check Bypass Filter	●						
Check and redo Bypass adjustment				●	●	●	●
Inspect/Replace Dilution Air Conditioner fan filter				●	●	●	●
Mechanical cleaning of tunnel/probe						●	
Inspect Heater/tunnel fans					●		
Inspect/replace tunnel gasket					●	●	
Measure background contamination							●
Replace O-Rings						●	
Check for leaks at interconnecting - Torque fittings							●

AVL-483, Micro Soot Sensor

The maintenance for an *AVL-483 Micro Soot Sensor* cannot be described by operating hours or number of measurements, but rather by the amount of soot that is present in the equipment[41]. However there are some guidelines that ensures that a problem free operation is maintained, see Table [E.5].

Table E.5: Maintenance Routines - AVL-483 MSS

Maintenance Activity	**Instant**
Purging of sampling lines.	When significant pollution is visible Automatic purging is performed at each transition from operating state "SLEEP" to "PAUSE" if shop air is connected
Replace the filter in the exhaust path.	Check Daily. Replace if one of the following conditions is met: • Flow warning is output. • Markedly visible soot layer (From 0.5mm thickness onwards).
Cleaning of measuring cell window.	• The related message is output. • Zero signal has a value of 1.5mV
Cleaning of glass tube in the measuring cell.	If the value of the zero signal does not decrease below 1mV although the measuring cell window have been cleaned.
Leak check.	Device has been newly installed. Device has been newly commissioned.
Replacing the filter in the exhaust gas path (installed at the from of the AVL Exhaust Conditioning Unit).	Check daily. Replace if one of the following conditions are met: • If the warning "No dilution air" is displayed. • Markedly visible soot layer (from 0.5mm thickness onward).
Cleaning of orifice, spring and dilution cell.	At intervals of approx. 200 operating hours, with heavy soot loads, however, every 100 operating hours.

AVL-489, Particle Counter

The maintenance of the *AVL-489 Particle Counter* consists of different service intervals[42]. Some of the maintenance is performed by the equipment itself while other require an operator/technician to perform the maintenance. Table [E.6] gives an overview of the maintenance schedule.

Table E.6: Maintenance Routines - AVL-489 Particle Counter

Maintenance interval / Service life	**Component / Action**	**Maintenance**	**Action**
Daily.	Leak check.	Check.	Automatically each time when switching on the system.
Daily.	Function test.	Check.	Automatically each time when switching on the system or manually.
Daily.	Venturi filter.	Check.	Remove condensate.
Always when refiling / emptying the butanol tanks.	Visual leak check.	-	-
Every two to four weeks.	Butanol.	Replace.	See manual[42].
Monthly.	Filter.	Check / Replace.	Change the filter.
Monthly.	PNC.	Check.	Check PNC flow.
Monthly.	Under-pressure leak check.	Check.	See manual[42].
Every 50 operating hours.	Venturi filter.	Replace / Clean.	See manual[42].
Every 200 operating hours.	Venturi pump.	Cleaning.	See manual[42].
Half-yearly.	Gas check or On-site check.	Check.	See manual[42].
Yearly.	Filter mats.	Replace.	See manual[42].
Yearly.	Calibration.	Check.	See manual[42].
Yearly.	HEPA filter.	Replace.	See manual[42].
Every two(2) years.	PNC pump.	Clean or replace.	See manual[42].

HORIBA-SPCS, Solid Particle Counter System

The maintenance for the HORIBA-SPCS consists of cleaning the particle counter, and performing various checks to confirm the functionality[43].

Table E.7: Maintenance Routines - HORIBA-SPCS, Solid Particle Counter System

Component / Part	Instant	Maintenance	Replacement
Flow check	Semi-annually	Perform Flow check	-
Pumps	Annually	Check functionality, Blades length minimum 14mm	When broken
Sample lines	Annually	Clean	-
Oricfice PND1	Annually	Clean	-
HEPA filters	Annually	-	Change
Pressure sensors	Annually	Perform Calibration	-
Leak check	Annually	Perform	-
CPC Status	Annually	Check status	-
CPC Sample Check	Annually	Check status	-
CPC Flow check	Annually	Calibrate	-
PCRF Calibration	Annually	Calibrate	-

AVL-I60 SESAM, Exhaust Gas Emissions Measurements

The maintenance for the *AVL-I60 SESAM* consists of daily, weekly, monthly and annual maintenance procedures of the two spectrometers[44]. Most of the maintenance can be performed by in-house personnel while some maintenance require trained experts from *AVL*. In the following four tables are the maintenance procedures described. Tables [E.8] and [E.9] describe the in-house and *AVL* maintenance procedures for the *Antaris IGS* Spectrometer, while tables [E.10] and [E.11] describe the in-house and *AVL* maintenance procedures for the *2030HY* spectrometer.

Table E.8: Maintenance Routines - AVL-I60 SESAM - Antaris IGS Spectrometer In-house Procedures

In-House Maintenance		
Maintenance	**Instant**	**Procedure**
Fill the device with liquid nitrogen	Daily	Filling the liquid nitrogen cooling of the detector
Cleaning the device (surface)	Monthly	Cleaning spectrometer
Check and replacement if necessary of the drying agent	Annually	Check and replace if necessary of the moisture indicator and the drying agent
Check and replacement if necessary of the moisture indicator	weekly	Check and replace if necessary of the moisture indicator and the drying agent
Check and replacement if necessary of the fan filter	Monthly	Check and is necessary replacement of the filter on the case fan
Check of the fan at the power supply and replacement if necessary	Monthly	Check and replacement if necessary of the power supply
Check of the Dewar performance	Annually	Check of the Dewar performance

Table E.9: Maintenance Routines - AVL-I60 SESAM - Antaris IGS Spectrometer AVL Procedures

AVL Maintenance per month/hour pump running time			
Maintenance	**3/1,500**	**6/3,000**	**12/6,000**
Cleaning of the gas cell in the spectrometer			●
Cleaning of the gas cell in the spectrometer with steam jet or ultra sound bath			●
Check of the gas cell window in the spectrometer			●
Check and replacement if necessary of the case filter			●

Table E.10: Maintenance Routines - AVL-I60 SESAM - 2030HY Spectrometer In-house Procedures

In-House Maintenance		
Maintenance	**Instant**	**Procedure**
Cleaning the device (surface)	Monthly	Cleaning spectrometer
Fill the device with liquid nitrogen	Daily	Filling the liquid nitrogen cooling of the detector
Check of the Dewar performance	Annually	Check of the Dewar performance

Table E.11: Maintenance Routines - AVL-I60 SESAM - 2030HY Spectrometer AVL Procedures

AVL Maintenance per month/hour pump running time			
Maintenance	**3/1,500**	**6/3,000**	**12/6,000**
Cleaning of the gas cell in the spectrometer			●
Cleaning of the gas cell in the spectrometer with steam jet or ultra sound bath			●
Check of the gas cell window in the spectrometer			●
Check and replacement if necessary of the drying agent			●
Check and replacement if necessary of the case filter			●

Horiba-Mexa 7000-Series Exhaust Gas Emissions Measurements

The maintenance of the Horiba Mexa 7000 units consists of cleaning the analyzers, performing pump flow and functionality checks. While also checking the analyzers[45].

Table E.12: Maintenance Routines - HORIBA-MEXA Emissions System

Component / Part	Instant	Maintenance	Replacement
Temperature settings	Semi-annually	Check temperature settings	-
Sample pump	Semi-annually	Renovate	When broken
Vacuum pumps	50hr operation time	Renovate	When broken
Vacuum test	After renovation of pump	-	-
Circulation pump	Semi-annually	Check functionality	-
Heated filter	Semi-annually	Change	-
FID	Semi-annually	Clean and change o-rings	-
Leak test THC and NO_x	Semi-annually	-	-
Exhaust Flow-Check	Semi-annually	Check Zero/span flow	-
APR flow	Semi-annually	Purge and check flow	-
Analyzer	Semi-annually	Check settings	-
Interferences test	Semi-annually	Perform test	-
No_x-converter test	Semi-annually	Perform test	Check and change converter material
Linearize analyzers	After maintenance	-	-
Fan Filter	Semi-annually	Check and clean	-

E.2 Routines - Conditioning Systems

The conditioning equipments consisted of different units that prepare the fuel and air to the engine and test cell.

AVL-753c, Fuel Temperature Control

The *AVL-753c Fuel Temperature Control* has an automatic warning system that warns when the equipment requires maintenance. However, some filter may be required to be changed or cleaned each quarter[46]. Table [E.13] describes the maintenance of the *AVL-753c Fuel Temperature Control*.

Table E.13: Maintenance Routines - AVL-753c Fuel Temperature Control

Components	**Service interval / lifetime**	**Maintenance**	**Replacement**	**Method**
Leak check of fuel circuit.	Weekly	Visual Check	-	-
Fuel Filter.	Depends on the return flow contamination max. 1000 hours	-	After Warning (at least 4 times per year)	Replacement
Return filter option.	Depends on the return flow contamination max. 1000 hours	After Warning (at least 4 times per year)	Replacement required after cleaning 4 times	Clean in ultrasonic bath or with compressed air, then replace.
Venting filter.	Depends on the return flow contamination max. 1000 hours	After Warning (at least 4 times per year)	Replacemant required after cleaning 4 times	Clean in ultrasonic bath or with compressed air, then replace.
Dirt trap, circuit filter.	Depends on the return flow contamination max. 4000 hours	After Warning (at least 2 times per year)	-	Clean in ultrasonic bath or with compressed air
Cooling valves.	25 milion actuations	Sealing test twice per year.	After warning	Replacement.
Overflow valve.	Max. 4000 hours	Visual inspection of valve ball for wear.	After warning.	Replacement
Main flow valve.	1 million actuations.	-	If faulty	See manual[46].
Venting valve	Replacement after 500 000 actuations, maintenance after 1000 actuations.	Sealing test twice per year or if error “Execute maintenance” is output.	After 500 000 actuations	See manual[46].
Fuel pump.	10 000 hours.	Sealing test 4 times per year.	After warning.	See manual[46].
Fuel switch.	30 000 hours	Sealing test 4 times per year.	After warning.	See manual[46].
Flow switch.	30 000 hours	-	After 10 000 hours	See manual[46].
Flow switch, cooling water circuit	30 000 hours	-	After 10 000 hours	See manual[46].

Water circuit and heating option	Depending on cooling water temperature and conditioning. max. 4000 hours.	Decalcify at least 2 times per year or when error “Execute maintenance” is output.	-	Cleaning the complete water circuit using a cleansing agent, See manual[46].
Dessicator pouch for option heating.	2 times per year or monthly. When condensate formation is high.	2 times per year or if required.	After every check.	Remove cover from heating element and replace dessicator pouch. Perform visual check of safety thermostat.
Motor fan. Fan electrics box.	Weekly.	Visual check.	Intake filter, extracted air filter-	-

E.3 Routines - Measurement Systems

AVL-735s, Fuel Mass Flow Meter

The *AVL-735s Fuel Mass Flow Meter* require two kinds of maintenance, weekly and indicated maintenance[48]. The weekly maintenance ensures that the device is operating properly, while the indicated maintenance indicates when some specific maintenance is required.

Weekly maintenance

Perform:

- Zero consumption measurement

Check:

- Compressed air switch
- Float switch
- Emergency stop relay
- Tightness of fuel circuit
- Filter mat
- Check effectiveness of fan

Indicated maintenance

- Fuel pump, after exceeding the maintenance limit (5000 operating hours)
- Fill valve, after exceeding the maintenance limit (100 000 switching operations)

AVL-740, FuelExact

Maintenance for the *AVL-740 FuelExact* is described by maintenance that shall be performed weekly, quarterly, annually and after a certain amount of switches, see table [E.14]. The calibration of the device is also performed annually, with an more extensive calibration every third year[47].

Table E.14: Maintenance Routines - AVL-740 Fuel Exact

Maintenance Interval	**Component**	**Maintenance**	**Replace**
Weekly	Emergency Stop	Check	-
	Overflow detector including safety chain	Check	-
	Fans and filter mats	Check functionality of fans, filter mats and device ventilation	filter mats (if necessary, depending on the degree of soiling, at least once per year)
	Tightness of fuel circuit	Visual check	-
	Tightness of water circuit	Visual check	-
	Water filter	Check and clean if necessary	depending on the degree of soiling
	Fuel circuit	Zero consumption measurement	-
Quarterly	Cooling valves and cooling pre-circuit	Leak check	In case of leak Replacement interval: Warning after 20 million operation cycles.
	Strainers	Visual check and cleaning of sieves	Replacement interval: Depending on the degree of soiling
	Measuring circuit pump, pre-circiut pump	Check function, leak check	After defect Replacement interval: Warning after 8000 operating hours
	Water pump	Check function, leak check	After defect Replacement interval: Warning after 8000 operating hours
	Venting valve	Zero consumption measurement	In case of leaks
	Optional shut-off valve	Check	If not functioning correctly

Maintenance Interval	**Component**	**Maintenance**	**Replace**
Annually	Safety valve in water circuit	Check	If not functioning correctly
	Leak check of check valve	Check	If not functioning correctly
	Measurement of circuit pump	Check and replace if necessary	Replacement inteval: Warning after 8000 operating hours
	Pre-circuit pump	Check and replace if necessary	Replacement interval: Warning after 8000 operating hours
	Water pump	Check and replace if necessary	Replacement interval: Warning after 8000 operating hours
	Fill valve	Check and replace if necessary	In case of leaks Replacement interval: Warning after 20,000 operating hours
	Cooling valves and check valves	Check and replace if necessary	Replacement interval: Warning after 20 million operating hours
	Cooling valve pre-circuit	Check and replace if necessary	Replacement interval: Warning after 20 million operating hours
	Strainers	Replace sieves	Replacement interval: Depending on the degree of soiling
	Fuel filter insert	Replace sieve	After defect Replacement interval: Depending on the degree of soiling Annual replacement is recommended
After 100,000 switching cycles	Fill valve	Leak check	In case of leaks Annual replacement is recommended
Depending on the degree of soiling, at least after 1,000 operating hours	Fuel filter insert	Check	Replacement interval: Depending on the degree of soiling

AVL-365c, Angle Encoder

The *AVL-365c Angle Encoder* requires maintenance at specific intervals to ensure a failure free operation[49]. The maintenance is described either by operating hours or after a certain amount of time, see Table [E.15].

Table E.15: Maintenance Routines - AVL-365c Angle Encoder

Maintenance intervals	Activity
Monthly or at least after 500 operating hours: **Check angle encoder**	• Check the mounting to engine (Check for loose screws). • Check adjustment of support arm to support (using the supplied adjusting sleeve) and also make sure that the support arm is clamped tightly to the support. • Check clearance of ball joint if in use (max. 0.15mm). • Check the flexible hose and connect cable for damage or danger of kinking. • Check the bearing clearance of the angle encoder housing to the sahft.
Before every mounting and after every removing of the angle encoder. **Check bearing unit**	• Check the angle encoder shaft. It should not show any noticeable axial or radial clearance in relation to the housing. • Check if the rotation is smooth and not jerky. • Change the bearing unit, if defective.
Once or twice a year: **Check marker disk and lens**	Depending on operating conditions, marker disk and lens might become solied with small amounts of bearing grease. 1. Screw of the angle encoder cover and clean the lens in the cover, the inside of the cover and the visible side of the marker disk. 2. Make sure the gasket ring is seated properly. Remount the cover and tighten the screws with 1.5Nm. If the marker disk was not removed, the assignment of trigger to engine need not be set anew. • in the event of heavier soiling, remove the marker disk and clean the entire inside area of housing and cover.

E.4 Routines - Utility Systems

AVL-622, Indimodul

The *AVL-622 IndiModul* require maintenance in the form of cleaning the device with dry and oil-free compressed air[50]. Furthermore, it is required that the functionality of the internal fans is operating properly.

- Check proper functionality.
- Check for damage to bearing (any fan that is making an unusual noise should be replaced).