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Masters Thesis

Operation Classification of Heavy Vehicles

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Abstract

Within Scania there is a need to classify vehicles depending on the prevailing operation conditions. Different vehicles are exposed to various loads and this will influence the need for R&M greatly. The systems that are presently used for classification purposes are subjective and the owner's negotiation skills can affect the outcome. Simultaneously there is a lack of knowledge concerning the influence specific factors have on vehicle wear.

The goal with the project was to develop a method which could be used for classification, based on information that is possible to measure. Information which can be extracted from the engine control unit, which all vehicles are equipped with, served as a starting point. This type of data is commonly called operation data. Since a new classification, in order to be meaningful, must be based on factors which influence the need for R&M activity it became an important part of the project to identify such factors.

In order to investigate the connection between operation data and wear several different types of information were evaluated and used. In the initial analysis operation data was compared with warranty information but no link could be discovered. The conclusion was that warranty information is unsuitable for the evaluation of operation data. Warranty information mainly reflects problems which arise due to quality problems and not due to wear.

Problems caused by wear can be expected to develop over time. Hence, it is important to have access to R&M statistics which cover a rather longer period of time. The only source of information available within Scania which contain comprehensive R&M information is RAMAS, used by the market organisation to evaluate R&M contracts. Unfortunately it is in most cases not possible to access operation data from contract vehicles. A collection of such data has been initiated but an evaluation of the material was not possible to fit within the timeframe of the project. However, an analysis of the available material showed that there most likely is a connection between wear on certain parts of the drive train and fuel consumption.

The collection of operation information requires a coordinated strategy. Investigating why damage is initiated and how it propagates is important to identify crucial operation factors. A thorough analysis of operation data needs to be done and the connection between wear and fuel consumption must be verified. A classification system based on the influence of operation conditions will not be static but develop over time.

*The picture on the front page shows a Scania P114 CB6x6 340 tipper and is taken by Dan Boman.

Sammanfattning

Inom Scania finns det ett behov av att klassificera fordon efter rådande driftförhållanden. Olika fordon utsätts för väldigt skilda belastningar och detta påverkar behovet av reparationer och service. De system som i nuläget används för klassificering är subjektiva och grunder sig mycket på uppgifter från fordonets ägare. Samtidigt finns det förhållandevis lite kunskap om hur specifika faktorer inverkar på slitaget.

Målet med projektet var att ta fram en metod för klassificering som grundar sig på mätbara data. Som utgångspunkt användes information som kan läsas ut ur den motorstyrenhet som samtliga fordon är utrustad med, så kallad driftdata. Eftersom en klassificering, för att vara meningsfull, måste grunda sig på faktorer som har inverkan på behovet av reparationer och service blev en betydande del av uppgiften att försöka identifiera sådana.

För att undersöka kopplingen mellan driftdata och slitage utvärderades och användes flera olika typer av information. I den inledande analysen jämfördes driftdata med garantiuppgifter men någon tydlig koppling gick därvid inte att finna. Slutsatsen blev att garantidata inte är lämpligt att använda för utvärdering av driftdata. Garantidata speglar främst problem som uppkommit beroende på bristande kvalitet och inte på grund av slitage.

Fel som uppstår som ett resultat av de driftförhållanden som fordonet verkar under utvecklas över tiden och därför är det viktigt att ha tillgång till reparationsstatistik som täcker en längre period. Den enda informationskälla inom Scania som innehåller heltäckande information om service och reparationer är en datorbas RAMAS där uppgifter om bilar med servicekontrakt lagras. Tyvärr finns det inte några driftdata att tillgå för det stora flertalet av de här bilarna. En insamling av driftdata från bilar med servicekontrakt har påbörjats men en fullständig utvärdering av materialet rymdes inte inom tidsramen för projektet. En genomgång av det material som trots allt fanns att tillgå visade på ett troligt samband mellan slitage på drivlinan och bränsleförbrukning.

Insamlingen av driftdata kräver en övergripande strategi. Förståelse för hur skador uppkommer och hur de sedan utvecklas med tiden är viktigt för att kunna identifiera intressanta driftfaktorer. En grundlig analys av driftdata behöver göras och kopplingen mellan bränsleförbrukning och slitage måste verifieras. Ett klassificeringssystem som bygger på hur driftfaktorer påverkar fordonet kommer att behöva förändras över tid.

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Foreword

This report constitutes my Masters Thesis and is the result of a project at Scania Technical Centre in Södertälje. The project was initiated in October 2003 and finished in the beginning of spring 2004 and was the last part of my degree in Industrial Engineering and Management. The Department of Industrial Management and Logistics at Lund Institute of Technology has been supervising the project, providing valuable insight and help along the way.

To work with this project has been challenging in many ways and I value the experience and knowledge it has given me greatly. I would like to thank all the people at Scania and its subsidiaries who have helped me in different ways.
The library at Scania has been a great resource during the project and have I am very grateful for the help the library staff has provided.

Special thanks to both of my supervisors Andreas Renberg at Scania and Bertil Nilsson at Lund Institute of Technology.

Södertälje March 2004

Fredrik Johansson

Abbreviations

CBM	Condtion Based Maintenance
FBM	Failure Based Maintenance
GTW	Gross Train Weight
OBM	Opportunity Based Maintenance
OEE	Overall Equipment Efficiency
PM	Preventive Maintenance
R&M	Repair and Maintenance'
TPM	Total Productive Maintenance
TQM	Total Quality Management

1 Introduction

1.1 Scania - The history[1]

In 1911 Scania, then located in Malmö, merged with Vabis from Södertälje. The new company decided to focus on trucks that could replace the horse and wagon. Already in the early days the company focused on developing fuel efficient engines. In the early twenties Scania launched a new engine that could be adapted to use several different sorts of fuel. Customers could simply switch to the most economical fuel at the time by changing pistons. The new engine was the first step towards the module-concept, which Scania is presently famous for.

Scania's first in-house engine was presented in 1936 and was a 6-cylinder diesel with 120 horse powers. Heating inside the cab was still fifteen years away. The engine development- and production-program continued to grow over the years with a great number of new products being introduced. The focus came to be on high-output engines that could operate on low engine speeds, this being beneficial for fuel economy, noise and service life. The first V8, introduced in the late sixties, was the result of a longer period of development efforts.

As the engine output grew there was a greater need for stronger chassis, different brakes and more advanced suspension. Scania had learnt a great deal about loads on different truck components, partially because the company supplied trucks to units within of the Swedish army. This knowledge became a great advantage and it influenced new designs.

The maintenance of trucks has changed a great deal over the years. Originally most trucks were maintained by their owners and only a very simple service organisation existed, engine overhauls were common. As heavy vehicles became more and more complex, Scania started to build a dense network of service workshops with trained staff. At the same time more service-friendly designs where emphasised. In the 1980's, Scania started to develop new maintenance programs whereby no repairs should be required only regular maintenance and replacement of certain parts. In the last thirty years the hours of maintenance needed have decreased between twenty-five and fifty percent.

[1] Scania, *Scania World Special edition*, 2002, p 2-7.

1.2 Scania - Today[2]

At present Scania is the only pure heavy truck producer in Europe. Compared to its competitors Scania is not a very large firm but a highly successful one with profitability better than any other company in the business. The success of Scania is the result of a very clear strategy focusing on the development and production of heavy vehicles.

Scania was the first vehicle producer to incorporate a modular system. The idea behind a modular system is to meet the widest possible demand with the minimum number of components. This is achieved using a standard interface for all the different parts. The customers can then combine these parts, within certain limitations, to meet their specific needs. The modular system has several advantages. First of all Scania does not need to develop as many different variations as would otherwise have been the case. Using a modular system the same basic designs can be used in a number of different products. So are for example several of the engine-components used for all of Scania's engines. Another advantage with a modular system is that the number of components needed in the production is limited. This makes the whole production-process less complex and easier to co-ordinate. A less complex system with fewer parts to coordinate is more efficient and cheaper to run.

Scania develops and manufactures all of the major components required themselves. Particularly in the United States, where Scania is not present in the marketplace, it is otherwise common for manufacturers to build cabs and chassis only. A second company, determined by the final customer, then provides the power train. To sell trucks equipped with an in-house power train as Scania does, gives a company greater possibilities to control the value chain. Furthermore the different components can also be designed to match each other early on in the development phase.

The initial investment, that is the purchase price, is only a small part of the total operating cost for a truck and many other factors are just as important. For Scania it is hence becoming increasingly important to provide the customer with a number of enhanced services. Finance as well as repair and maintenance are vital areas when trying to attract customers. The life cycle cost for a truck is illustrated in figure 1.

[2] Scania, *Det globala Scania,* 1997, p 2-18

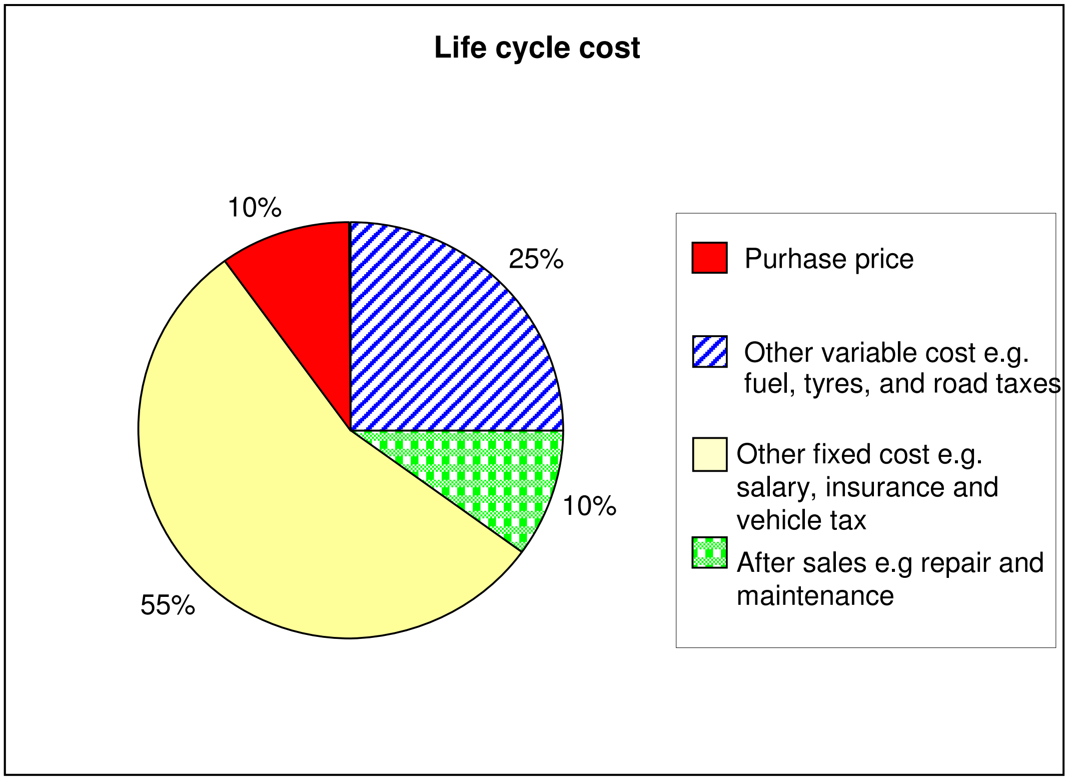

Figure 1. Life cycle cost for truck

1.3 Background

Scania vehicles are comprised of modules and customers can, within certain limits, combine these in any way they find suitable. With so many possible variations there is no standard product. However, several of the many possible combinations are more common than others.

Within Scania and its subsidiaries there is a need to group vehicles into larger categories depending on how they are used. To classify vehicles depending on the situation of operation is useful in several ways. Firstly the need for repair and maintenance (R&M) is dependant on the situation. Knowledge about how a specific vehicle is operated can help the R&M organisation adjust the maintenance program for the particular situation. Likewise, if the type of operation is known, a salesman will have a greater chance to help the customer to find an optimal specification for a new vehicle. It is also important when designing new products to understand how the products actually will be used since this might affect the development project.
Today the grouping of vehicles varies between different departments of Scania depending on which perspective is being used. For example, the sales-,

workshop- and warranty-organisations all have various classification systems. With several different systems it is necessary, in order to avoid misunderstandings, to clarify which system is being used. In addition to the fact that several different classification systems make it hard to utilise the operation classification all together, the classification itself is very subjective. Few of the operation factors taken into consideration are possible to measure and the classification is partially a result of bargaining between the sales staff and the customer. An exmple of operation type classification can be seen in table 1.

Table 1. Example of operation type classification

Operation type	Type 0	Type 1	Type 2	Type 3	Type 4
Characteristics	•Light long haulage •Good road conditions •General cargo •GTW <40 tonnes	•Long haulage •Good road conditions •General cargo •GTW 40-60 tonnes	•Long haulage •Poor road conditions •Timber, bulk •GTW >40 tonnes	•Construction operations •Off-road •Gravel, concrete	•Short haul distribution •Good road conditions •Distribution

An objective classification system based on measurable operation parameters could have many advantages. Most importantly the different operation types would be clearly defined. Hence, classification could be performed the same way in the entire organisation. However, in order to be meaningful a classification system must be based on parameters which link operation conditions with the effect on the vehicle. The road conditions, the topography, the driver, the weight of the vehicle, the vehicle specification and vehicle speed are several examples of the many factors that influence the vehicle. Unfortunately there is a great level of uncertainty when it comes to quantifying the effect that each of these have on the truck since the relations are very complex. Nonetheless it is crucial to investigate the link between operation conditions and vehicle wear.

Knowledge concerning vehicle operation and its effect on the vehicle can be used for numerous purposes. In coordination with other types of information such as customer data, vehicle data, repair data and registration data, operation data can be utilized extensively both locally and centrally. Being aware of both customer requirements and vehicle information makes it possible to offer customers services in accordance with their needs, see also figure 2.

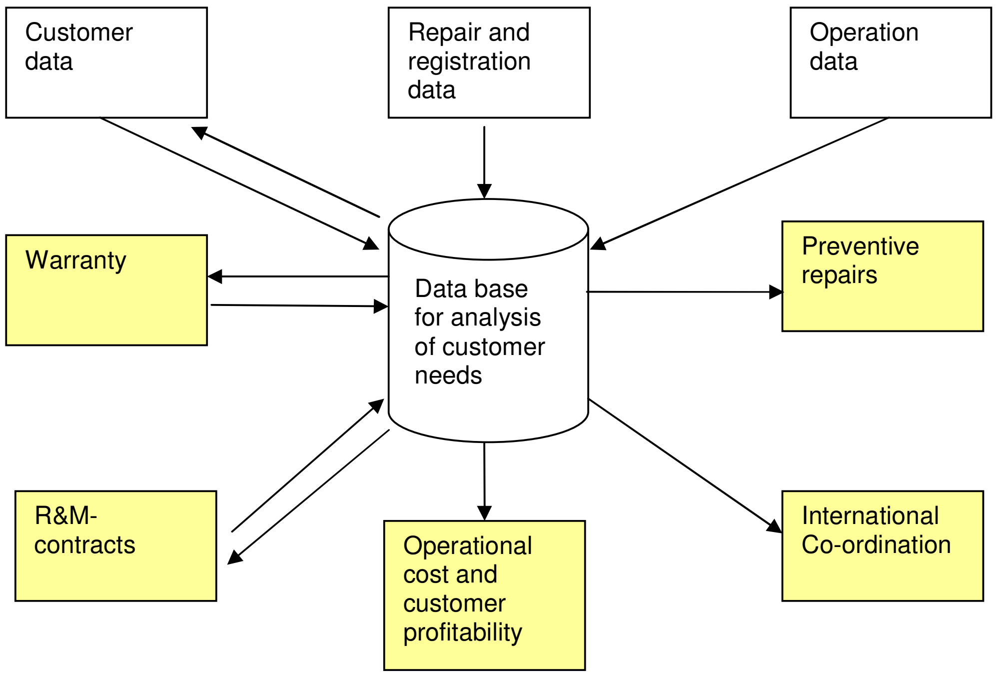

Figure 2. Data warehouse with customer and operation data

1.4 Formulation of problem

With the starting point in operation data extracted from trucks, how should we go about to develop an objective method for classification? The classification system must be based on variables which are related to vehicle wear. How can such variables be identified?

1.5 Goal

The main aim of the project is to develop a new objective method for classification of vehicles. Operation type classification will be important in for example the design and pricing of maintenance contracts and how new vehicles are specified.

Through collection and analysis of vehicle data and operation data from the engine control unit a method will be developed. The power train (the engine) and drive train (see table 1) will work as starting points for the project as they are directly influenced by engine operation.

Table 2. Parts included in the power train and drive train

Engine	Clutch	Gear box	Prop shaft	Rear axle

1.6 Target group

The report is primarily intended for employees within Scania and its subsidiaries.

1.7 Delimitations

This project focuses on a method which can be used for development of a new objective operation type classification. Thus, the result of the project will not be an entirely new classification system but a starting point for further work within the area.

1.8 Source limitations

Only one truck out of a thousand sold by Scania is currently represented in the database which contains operation data from the engine control unit. The reason for such a small proportion of the engine data being stored is that an overall strategy for the gathering of such information is lacking. For a long time read-outs of operation data has been something which the workshop does occasionally when the vehicle is in for R&M. However, since there is no real incentive for the workshop to forward the information to Scania Technical Centre, where it is stored in a database, the gathering of data is quite sporadic.

Operation data must be evaluated and used with care. Some of the vehicles in the database have had the information in the engine control unit memory extracted because they repeatedly break down or perhaps have a problem that puzzles the workshop employees. By extracting operation data and perhaps send it to someone at the head office for evaluation the crew often hope to find a clue to what the root cause of the problem is. Thus, it can be questioned whether the operation data sent to Scania and incorporated in the database is representative for Scania vehicles in general.

R&M-data is recorded only for vehicles which are serviced by Scania and its subsidiaries in accordance with a service contract. Not every customer is interested in a R&M contract when buying a new vehicle as they might have their own repair shop or use another workshop which is not connected to Scania in any way. These vehicles are not represented in the R&M statistics.

Some types of vehicles are not commonly sold with an R&M contract. This is for example the case for trucks built on chassis of Distribution- (D) and Construction- (C) type. These trucks are usually driven rather short distances in restricted geographical areas making the owners less prone to sign R&M-contracts. However, Scania predominantly sells vehicles used for varying sorts of long-haulage and many of these vehicles are bought with an R&M-contract. The database containing R&M info is thus somewhat representative for the production mix within Scania.

1.9 Outline of the report

Chapter 2, *Method* aims at presenting the method which has been used throughout the project. Validity and reliability are described both generally and in the context of the project. Finally the relevance of the report is discussed.

Chapter 3, *Theory*, aims at describing the theory which serves as a starting point for the project. Machinery failure and different aspects of maintenance are presented.

Chapter 4, *Vehicle information*, describes the different resources, containing vehicle information, which are available within Scania. Characteristics of these resources are outlined and discussed.

Chapter 5, *Analysis of warranty data*, investigates the relationship between operation data from vehicles with data concerning warranty issues.

Chapter 6, *Analysis of repair and maintenance (R&M) data,* investigates the relationship between operation data from vehicles and R&M information.

Chapter 7, *Conclusions and recommendations*, describes the result from the analysis and the most important conclusions. Finally recommendations for further work within the area are presented.

2 Method

Initially the author's frame of mind and the impact it has on the research is discussed. After a short introduction, concerning a few of the possible research methods and their characteristics, the chosen working method for the project is described. Finally the relevance of the report is discussed.

2.1 The author's influence[3]

The author's understanding of the surrounding world has great implication for how the research is carried out and thus the final result. Our perception of the world around us influences the method we choose to conduct research and the way we analyse the results. However, as can be seen in figure 3, the influence our understanding has on how a specific research task is carried out is not single sided. The results will influence our idea about the reality and thus change our perception of this reality.

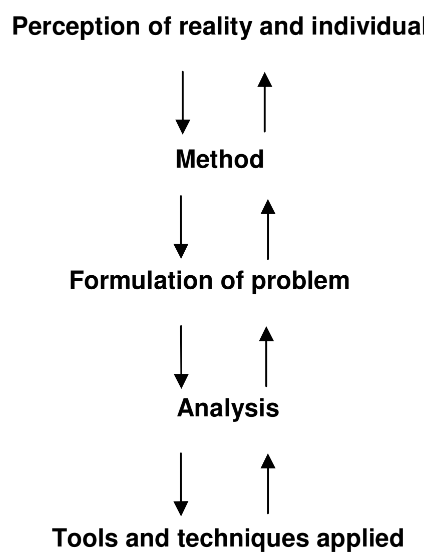

Figure 3. The interdependency of the researcher's perceptions and how research is carried out

Rather often the method applied in a certain situation is unspoken. We may have been in the same situation before and to consider all the different alternatives would according to our bias be both time consuming and a waste of resources. Nonetheless, it can occasionally be worthwhile to think about how suitable a

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[3] Darmer P, Freytag P, *Företagsekonomisk undersökningsmetodik*, 1995, p 24-27

certain method is and the implications it will have. First of all it can help the researcher to understand the limitations of a certain method and the underlying perception. Knowledge about these limitations can lead to a change in attitude which allows the view of the reality and the method to become better aligned with the overall aim of the research project.

Certain methods can be described very carefully but nonetheless only the researcher will have the knowledge to evaluate the information and its limitations. The method used must be carefully described so that choices and interpretations that have been made are easier to understand.

2.2 Research methods[4] [5]

There are always multiple choices when it comes to selecting a method. If a certain method is appropriate or not depends on the problem at hand and the resources and the competences of the researcher. The method must be suitable for the knowledge needs and the reality being studied. Among the available methods experiments, surveys, and case studies are the main ones.

Experiments are used to evaluate the cause and effect relationships between a number of variables. Conducting experiments is often rather complicated and time consuming. To some extent the researcher needs to be in control of the environment, blocking against certain factors influencing the result.

Surveys can be used to answer research questions of many different kinds but are commonly used when the research question is somewhat straight forward. A questionnaire or a standardised interview is used on a large population. The result is presented with different sorts of diagrams and tables, explaining how the respondents have answered when facing a certain question.

When a case analysis method is used the research focus on one or a few specific objects that are examined more on depth. Case analysis is especially suitable to use when it is hard to determine which factors that are important and makes it possible for the researcher to investigate relationships which was not initially thought of. The researcher has a great amount of freedom when conducting a case analysis both when gathering information as well as when analysing it. Case analysis can be a starting point for a later survey or experimental approach.

[4] Ejvegård R, *Vetenskpalig metod*, 1996, p 30-33
[5] Karlsson M, Lövdahl C, *Vägen till rätt kvalitet*, 2003, p 19

2.3 Methods for data collection[6] [7] [8] [9]

A number of different methods for data collection are needed in most research contexts. Usually a distinction is made between primary resources and secondary resources of information. Primary data is data that the researcher gathers while secondary data has already been documented by someone else. The level of freedom that the researcher has when choosing sources of information varies somewhat depending on how the research project is specified. The most commonly used ways to gather information are interviews, observations, database retrievals document reviews and experiments.

Document reviews are often a very efficient way to gather information concerning a specific field or subject. Knowledge about what other people have done before and what their conclusions were is an obvious starting point before any research is done within the same area. When reviewing documents it is important to consider that they were written for a specific purpose and with a specific audience in mind, this can greatly influence their reliability.

Interviews can be performed in ways which are more or less structured depending on the purpose with the interview. An advantage of using interviews that are not very structured is that the researcher can adjust the questions in accordance with what the respondent says making the interview very flexible. The problem with that is of course that it might be hard to analyse the data due to the diversity in response that might be the case. On the other end of the spectra are interviews which are carried out in exactly same way using standard questions which have been validated and tested. In order to be beneficial interviews must to be carefully prepared and analysed something which commonly requires quite a lot of skill and time.

Researchers can increase their knowledge about a certain system by simply observing it for a period of time. Observations make it possible for the researcher to draw conclusions which are not based on other people’s impressions. Just as with interviews, the researcher’s level of involvement can vary considerably. Direct observations does not contain any contact with the system itself, intervenient observations on the other hand require a high level of involvement from the researcher. Observations can only give increased knowledge about the present situation but does not provide any information about what has happened in the past.

[6] Lekvall P, Wahlbin C, *Information för marknadsföringsbeslut*, 2001, p 257-271
[7] Karlsson M, Lövdahl C, *Vägen till rätt kvalitet*, 2003, p 20
[8] Ejvegård R, *Vetenskaplig metod*, 1996, p 44-50
[9] Axelsson J, *Arbetsmiljödriven kvalitetsutveckling*, 1995, p 110-114

2.4 Quantitative and qualitative research[10] [11]

Qualitative research is concerned with observation, description and generation of hypotheses. The focus of qualitative research is to understand and explain complex situations and context. A researcher conducting a qualitative research task can use a wide range of different sources, the main ones being observation and informal conversation.

Quantitative research is used when the research question involves defined variables and a large number of objects. Quantitative methods are more structured and the researcher is in better control of the situation. The method is commonly used to explain or verify a number of different phenomenons.

Sometimes researchers combine quantitative and qualitative methods, depending on the research question. To use a combination of methods in order to improve the validity of the final result is called triangulation.

2.5 Reliability and validity[12] [13]

To evaluate results and information resources is a necessity. Otherwise there is a risk that the material is not interpreted in an appropriate way. For evaluation purposes the concepts of validity and reliability are commonly used.

Reliability addresses the correctness of a certain measurement instrument and a certain measurement unit. If, when the same measurement is repeated, the same value is recorded the method used is said to have high reliability.

Validity is concerned with if the measurement method used actually measures the appropriate property. When conducting research of qualitative type it can be hard to judge if the method used is valid or not since there is no one way to get the correct result.

Reliability and validity are connected to each other; high validity requires high reliability. However, high reliability does not in any way guarantee high validity. Measuring something the correct way does not rule out that the wrong thing has been measured.

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[10] Lekvall P, Wahlbin C, *Information för marknadsföringsbeslut,* 2001, p *213*
[11] Darmer P, Freytag P, *Triangulering – ett redskap i analys- och datainsamlingsprocessen*, 1995, p 123-127
[12] Lekvall P, Wahlbin C, *Information för marknadsföringsbeslut*, 2001, p 304-308
[13] Ejvegård R, *Vetenskaplig metod*, 1996, p 67-70

2.6 Working method

The project consisted of several parts. These included literature studies, data mining, analysis and finally conclusions and recommendations. The literature studies were mainly conducted to increase the understanding of general maintenance and the R&M business. During the data mining phase different data sources were evaluated and compared. The different sources all had certain characteristics and it was important to be aware of these before an analysis was carried out.

2.6.1 Literature studies

During most of the project literature studies have been carried out to help build a foundation of basic data for decision making. The areas that have been studied are mainly maintenance, in general as well as specifically for vehicles. In cooperation with personnel from the Scania library literature which in some way connect operation factors with the need for repair and maintenance has been investigated.

2.6.2 Data mining

There are a number of data sources available containing different kinds of vehicle information. All of these sources have been designed with a specific application in mind and the types of information they contain differ significantly. Thus, an important part of the project was to learn what these sources contain and how they can be characterised.

2.6.3 Analysis, conclusions and recommendations

To start with, the analysis was based on data already available within Scania. Once this analysis had been performed a review was made and it was decided that further work had to be based on material that was collected in cooperation with workshops in Sweden. Unfortunately the time allowed for the project was not enough to collect all the material that was needed in order to perform a complete analysis. The completion of the analysis had to be done after the termination of the project. Conclusions and recommendations in this report is thus based on the work that has been carried out so far.

2.7 Relevance of the report

The relevance of the report is deemed to be high meaning that the project is of interest not only for the researcher but also for other people. No similar published projects have been found and investigating the link between operational conditions and wear is in many ways important for Scania and its subsidiaries. Aftermarket sales are becoming increasingly important to manufacturers and knowledge concerning links between operation conditions and wear makes it possible for them to design more specific offerings to customers.

3 Theory

The aim of this chapter is to make the reader more familiar with theory concerning maintenance issues and other related areas. The complexity of maintenance issues and the issues involved are important throughout the project.

3.1 Neural networks[14] [15]

Neural networks have become increasingly popular over the last twenty years and their design is often compared to that of the human brain. Networks of this kind are used in areas of prediction and classification where other statistical techniques have traditionally been used. Highly interconnected simple computational units, also called nodes, are the main parts of a neural network.

Each connection in a neural network has a weight w associated with it which is adjusted depending on the problem presented to the network. The total input to one node is the sum of the output from nodes connected to it multiplied with the weight of that particular connection. Only if the total input a to a node is larger than a particular value θ will an output y be generated (figure 4).

$$a = W_1X_1 + W_2X_2 + \ldots + W_NX_N$$

$$a > \theta \Longrightarrow y = 1$$

$$a < \theta \Longrightarrow y = 0$$

Figure 4. Only if the input is large enough will an output be generated

The adjustment of connection weights is commonly called learning and can be either supervised or unsupervised. Under supervised learning there is a known target value which is compared with the output from the network and the weights are then altered accordingly. Thus, it is important to use a data set which is representative for training purposes. However, a neural network can also receive too much training, causing it to adjust to minor patterns which are perhaps only present in the training set. Unsupervised training is used when no target output values are available.

[14] Strandlund H, *Introduktion till artificiella neurala nätverk*
[15] Warner B, Misra M, *Understanding neural networks as statistical tools,* 1996

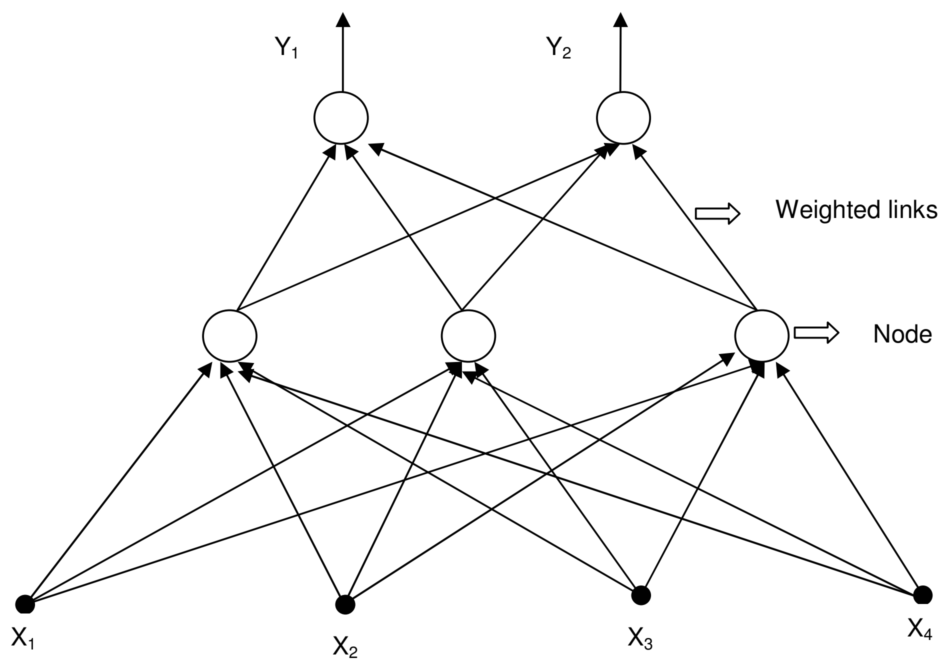

Figure 5. Schematic representation of a neural network

Neural networks can be used to find complicated connections in a large amount of data and it can be used within almost any science and applied on a variety of problems. There are numerous commercial software programs that can be used to implement neural networks. However, using neural networks is not an entirely straight forward exercise. Choosing input parameters, initial weights and how many layers of nodes to use requires a certain level of knowledge and experience. Neural networks are used in certain maintenance systems for condition monitoring purposes and will be further mentioned in chapter 3.5.3.

3.2 Machinery failure[16]

Machinery failure is any change which causes the equipment to be unable to function satisfactorily. Very often a failure is the final stage of a longer chain of cause and effect relationships. Failure analysis seeks to uncover the root cause of the problem and to rectify it in order to prevent future failure and to assure safety, reliability and maintainability of machinery as it passes through its life cycle.

[16] Bloch H.P, Geitner F.K, *Machinery Failure Analysis and Troubleshooting*, 1994, p 1-9

Failure causes can be classified in the following way:

- Unintended service conditions
- Improper operation
- Maintenance deficiencies
- Faulty design
- Material defects
- Processing and manufacturing deficiencies
- Assembly or installation defects

The first three points on the list, unintended service conditions, improper operation and maintenance deficiencies are especially interesting for this project. With appropriate sales and R&M procedures these ought to be possible to influence directly. The remaining four points might not be possible to affect immediately but knowledge concerning operation conditions and their effect will be of great importance over time.

3.3 Unintended service conditions

If the needs and wants of the customer are not properly understood by the manufacturer and its subsidiaries the customer might buy a product which is not optimised or maybe even unsuitable for the application the customer is interested in. A product being used for purposes it was not intended to be can be a nuisance for both buyer and seller. If for example the product is applied in the wrong setting maintenance and repair costs will typically be higher than what would have been the case if a more appropriate product was selected.

3.4 Improper operation

When new designs are developed they are optimized for a certain type of operation. When put into operation the resemblance between the actual use and the use the equipment was designed for can be quite different. For equipment manufacturers it is important to design systems which are easy to operate and not damaged when they are handled incorrectly. Competent operators are important for safe and efficient operation and can eliminate cost for equipment manufacturers as well as customers.
Increased load cycling, corrosion, unanticipated stresses and many other factors can then reduce the life expectancy of certain components[17]. Thus, the connection between the operating environment and the maintenance requirements are very strong. Often manufacturers use generous margins to be on the safe side. Thorough knowledge about customers and how they operate their equipment can help the company to develop more appropriate designs and to customize the maintenance program.

[17] Douglas J, *High value for condition assessment*, 1996, p 29

3.5 Maintenance

3.5.1 Introduction to maintenance[18] [19]

Maintenance deals with the "care and repair of equipment"[20] and is a multidisciplinary area. Keeping the equipment running in a cost effective way requires the maintenance organisation to perform tasks at the right time and in the right way. The approach to maintenance varies a great deal between different companies and different sorts of equipment. Some machines cannot be allowed to fail and maintenance therefore focuses on preventing errors to occur. In other cases there might be spare capacity available making the maintenance functions less critical. Numerous aspects must be taken into consideration before a decision regarding maintenance can be made.

3.5.2 Development within maintenance[21] [22]

Maintenance practice has changed a great deal over the years in response to different requirements. World events, legislation, corporate strategy, communications and many other factors all affect the maintenance function directly or indirectly. Early on maintenance was mainly an engineering field but the emphasis has shifted and now many other disciplines are also involved.

In the early days of industry maintenance was seen as hardly anything more than a necessary expense, which should be limited to the largest possible extent. The focus was entirely reactive; meaning that when something broke it was replaced or repaired to ensure the equipment run again. The overall efficiency of the total system was not considered to any larger extent.

In the middle of the 20th century the maintenance systems started to change somewhat. More and more preventive maintenance was carried out. Personnel continuously monitored the equipment and tried to determine the best methods to avoid failure, renew components and to reduce repair time. Specialisation made the maintenance organisation grow as the number of technicians increased.

During the last few years the emphasis of maintenance has shifted towards integration with other functions within the company. The goals of the maintenance function are becoming aligned with the corporate goals and maintenance is seen as an integrated part of the business which involves the entire organisation and

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[18] Jonson P, *The impact of Maintenance on the production process - Achieveing high performance*, 1999, p 25-27
[19] Wilson A*, Asset maintenance management*, 1999, p13-18
[20] Bessant J, *Macmillan dictionary of production management & Technology*, 1990, p 95-96
[21] Jonson P, *The impact of Maintenance on the production process - Achieveing high performance*, 1999, p 27-28
[22] Wilson A, *Asset maintenance management*, 1999, p 8-12

can help to increase the profit. Concepts such as Total Productive Maintenance (TPM) have been introduced and present ways to increase the interaction between different functions.

3.5.3 Maintenance concepts[23] [24] [25] [26] [27]

A number of different maintenance concepts have been developed in response to the development of equipment and need for reliable operation. Instead of leaving machines running until failure the trend has been to use a more proactive approach aiming at eliminating problems before they arise. As the emphasis of maintenance changes from repairing equipment which has failed to work in a proactive way the responsibility for carrying out maintenance generally becomes more decentralized. The most common maintenance policies are presented below:

Failure-Based Maintenance (FBM)

Under FBM no action is taken until a failure occurs, no maintenance is performed when the equipment is operating as intended. The task for the repair personnel is to restore the machine to its original state as soon as possible. FBM should be used mainly when breakdowns are random and the incurred cost is low. Studies referred to by Mobley[28] shows that repairs carried out after a failure are substantially more expensive than the same repair made within a use-based or condition-based mode. A large number of redundancies in spare parts are usually required under FBM, otherwise the time between failure and repair will become to long. At all times the required personnel must be easy to access, should a failure occur.

Preventive Maintenance (PM)

Using PM components are replaced at particular times, independent of its condition. This is intended to reduce the risk of failure and prevent degradation. The time between two replacements can be either calendar time or running time for the specific component. The cost of maintenance can be minimised selecting a suitable replacement interval. However, depending on the underlying distribution of failure selecting the optimal interval is not always an easy task.

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[23] Al-Najjar B, *Condition based maintenance: Selection and improvement of a cost effective vibration-based policy for rolling element bearings*, 1997, p 18-23
[24] Jonson P, *The impact of Maintenance on the production process - Achieveing high performance*, 1999, p 28-32
[25] Ljungberg Ö, *Att förstå och tillämpa TPM, Total Produktivt Underhåll*, 1998, p 20
[26] Olsson E, *Tillståndsbaserat underhåll-Projektplan*, 2002, p 1
[27] Starr A,. Estaban J,. Willets R, *Data fusion as a model for advanced condition-based maintenance*, 2002
[28] Mobley R.K, *An introduction to predictive maintenance,* 1990

Condition-Based Maintenance (CBM)

With CBM the condition of the equipment or the technical system is monitored with regular intervals or continuously. When an error is indicated the equipment is taken out of use and serviced before a serious failure occurs.

To monitor a system successfully it is necessary to have a reliable indication of the maintenance requirements. There are several different measurements which can be used to assess the condition of equipment for example temperature, vibration, pressure and acoustic emission. The measured value is compared to historic values and through knowledge about the system and its components it is then possible to estimate the future development of failures and risk. Thus, implementation of CBM requires that a clear link can be established between possible failures and a parameter which is measurable.
CBM is used widely within power- and process-industry where a failure can have a very large effect. As the cost of monitoring equipment declines the interest for CBM increases and also smaller companies with limited financial resources have started to use CBM. However, the more reliable the equipment that should be monitored is, the less cost effective is the implementation of CBM[29].

Condition monitoring carried out by operators can be seen as a type of CBM. Most failures can be avoided using the human senses to monitor the equipment. Maggard and Rhyne[30] state that 75% of the occurring problems could be prevented by the operator at an early stage.

Large machinery can often generate diverse condition indicators which are hard to use as data for decision making concerning maintenance issues. Data fusion, which is the process of combining data and knowledge from different sources maximising the amount of useful information, can be used to evaluate information from a more advanced monitoring system. In a CBM system containing several different kinds of sensors a significant amount of data needs to be processed when assessing the condition of the equipment. There are many different kinds of data fusion techniques and knowing when the different methods of data fusion are appropriate can require a great deal of experience. Neural networks is one sort of technique which can help to fuse multiple sensor input and even diagnose the condition and suggest actions that should be taken. The accuracy of the neural networks' prediction should improve over time as it learns more about the relationships present in the data.

[29] Rajan B.S, Roylance B.J, *Condition-based maintenance: A systematic method for counting the cost and assessing the benefits*, p 97-108
[30] Maggard B.N, Rhyne D.M, *Total productive maintenance: A timely integration of production and maintenance*, p 6-10

Opportunity-Based Maintenance (OBM)

With OBM maintenance work is carried out when utilization is low or the equipment is idle. Using OBM might result in delays for some types of maintenance. Large overhauls can be hard to schedule in the program since the equipment must be taken out of service for a longer period of time. Areas where OBM is typically used are for example within power- and process-industry where maintenance is scheduled long in advance.

3.5.4 Total Productive Maintenance (TPM)

Total productive maintenance is a concept which aims at improving equipment efficiency as much as possible. Operators are required to take over some of the maintenance tasks and are told to report any changes in machine condition to the maintenance staff. TPM tries to improve common practices in the organisation changing the corporate culture. The connection between TPM and TQM is strong and the Deming cycle i.e. Plan-Do-Check-Act is important in both of them. Continuous improvements and elimination of all kinds of waste is the focus of TPM.

3.5.5 Maintenance costs[31] [32]

Deciding on an appropriate level of maintenance is not a simple task. The cost of maintenance compared to the amount of down-time is not a linear one. Increasing the spending on preventive maintenance can, in some cases, even decrease the ratio between up-time and down-time. Maintenance is an integral part of the company and a tool to keep the value adding process running effectively. Therefore a suitable approach to maintenance requires knowledge about the whole system.

The direct cost for maintaining the assets such as personnel, spare parts and external services is rather easy to quantify. However, Ahlmann[33] points out that on average only half of the maintenance cost is direct maintenance cost. Hidden costs, mainly consequential costs of inadequate maintenance, can be totally dominating. An inventory kept to compensate for down-time, cost of over-time due to down-time and the cost of purchasing additional capacity are examples of such hidden costs. Decision models based only on direct cost can be completely misleading.

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[31] Watson A, *Asset maintenance management*, 1999, 29-36

[32] Jonson Patrik, *The impact of Maintenance on the production process - Achieveing high performance*, 1999, p 33

[33] Ahlmann H, Elfving G (Ed), *ABB Handbook Industry,* 1993

Equipment should be evaluated using the total aggregated cost during its full life-cycle. A large part of the performance is determined already during the design phase and it is important to consider maintenance cost and maintainability already in this stage. However, some measurements can be taken also when the equipment is running to reduce the need for maintenance. To monitor the 'consequence' maintenance cost is an important task, helping the organisation to allocate the appropriate level of maintenance resources for the specific equipment. Not taking the total life-cycle cost into consideration might cause a situation where only direct costs, the tip of the ice-berg, are accounted for.

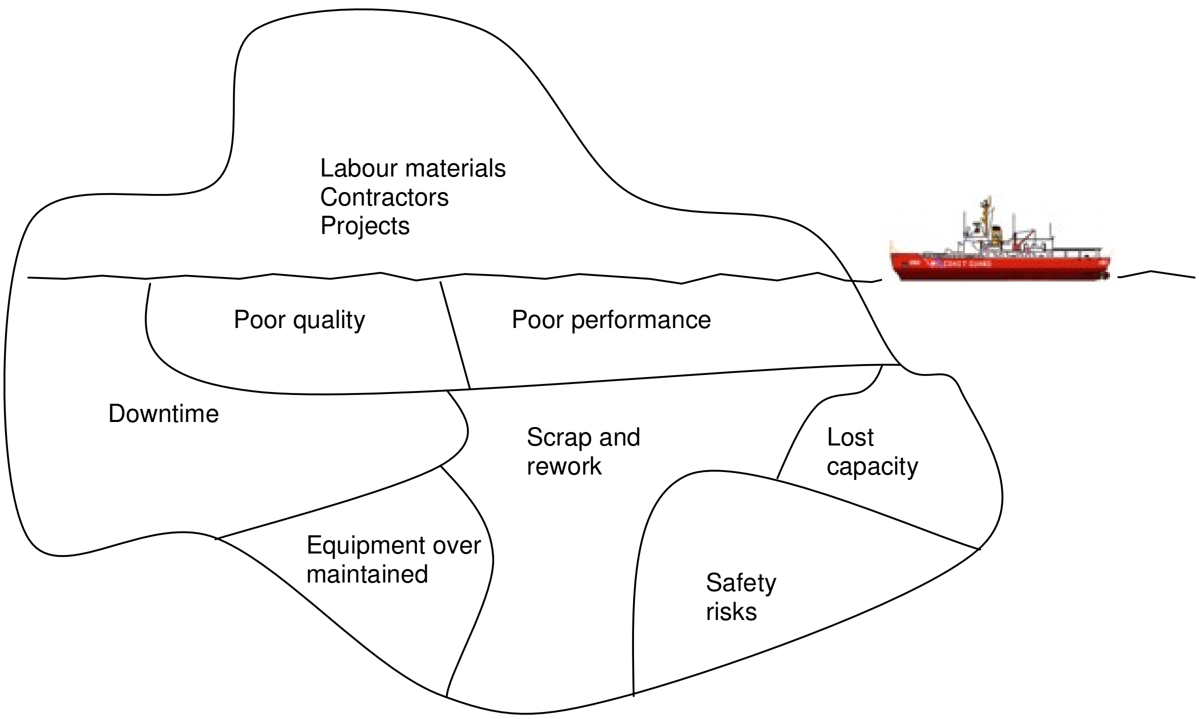


Figure 6. Direct costs are the tip of the ice-berg[34]

[34] Wilson A, *Asset maintenance management*, 1999, p 33

3.5.6 Maintenance aims and performance measures[35] [36] [37]

Maintenance is a service function which is mainly noticed when a fault occurs. However, maintenance is an important part when trying to achieve the companies overall business objectives and aims of the maintenance function must therefore be carefully aligned with corporate strategy. Only when the contribution of maintenance to the profitability is well understood can the function gain acceptance and appreciation within the organisation.

When measuring the performance of maintenance activities it would be optimal to track the contribution of maintenance to the life-cycle profit. However this is often not possible. A common approach is to look at maintenance costs and equipment availability. This takes account of sporadic failures, malfunctions that have significant effect when they occur but less so long term. Chronic problems, meaning that the equipment is not operating at the maximum of its capacity, are very common and often hard to recognise. The operator might for example not be aware of how to use the machine efficiently. To discover chronic failure the performance of the system must be compared to a potential level which is possible to reach. Performance measurements such as the overall equipment efficiency (OEE) measure and the up-time measure can be used to broaden the focus.

- OEE = Availability x performance efficiency x percentage of first quality products

- Up-time = Amount of time running on maximum capacity whilst making first quality products

3.6 Maintenance of vehicles

3.6.1 Introduction

Vehicles are from a maintenance point of view quite different from other types of equipment. The mobility and the changing operation conditions make it hard to monitor the condition of vehicles and determine appropriate maintenance intervals. Thus, maintenance is not to any larger extent adapted to the specific vehicle. The consequence is that many vehicles are maintained too often or too seldom, resulting in higher cost for maintenance and increased wear respectively.
In cases where the R&M interval is in some way aligned with operation conditions the maintenance organisation can many times not access any more information about the operation of the vehicle than what the owner provides. How a vehicle is

[35] Wilson A, *Asset maintenance management*, 1999, p 42-59
[36] Jonson P, *The impact of Maintenance on the production process - Achieveing high performance*, 1999, p 48
[37] Ljungberg Ö, *Att förstå och tillämpa TPM, Total Produktivt Underhåll*, 1998, p 25

actually used can however differ greatly from what the owner says and might also change over time.

The mobility of a vehicle sometimes makes it hard to provide R&M activities if it does break down. Furthermore, it is also hard to immediately replace for example a truck with spare capacity as might be possible with other types of equipment. To limit the impact of a malfunction requires an R&M network with extensive geographic coverage.

3.6.2 The Scania maintenance program

Maintenance requirements differ from one component to another and maintenance intervals are adjusted accordingly. Within Scania the recommended maintenance program can be subdivided into six different parts, each to be carried out in accordance with an overall scheme.

- D-maintenance: Carried out before the vehicle is delivered to customer
- R-maintenance: Carried out within four weeks of delivery during the running-in period
- S-maintenance: The least extensive type of maintenance carried out on a regular basis
- M-maintenance: Regular maintenance
- L-maintenance: Extensive maintenance compromising all the inspection points
- X-maintenance: Extra lubrication of the chassis

The D- and R-maintenance are only carried out once before and shortly after the vehicle has been delivered. The S-, M- and L-maintenance schemes are carried out on regular basis in a pattern: S-M-S-L........
The distance driven in between maintenance occasions depends on which operation type the vehicle is classified as and varies between 120.000 kilometres for type 0 (only if a certain engine oil is used) and 30.000 kilometres for type 4. In certain cases when trucks are idle or running other equipment through a Power Take Out for extensive periods of time maintenance intervals are adjusted accordingly.

The extra lubrication is not done on all vehicles depending on the prevailing road conditions but is otherwise carried out once in between regular maintenance occasions.

The current maintenance program is mainly based on the concept of preventive maintenance. Components are replaced with certain intervals to reduce the risk of failure and prevent degradation. However, the maintenance program also contains elements of failure based maintenance, some components are not maintained but expected to last the full lifetime of the truck.

Jobs

Most tasks in a workshop are carried out regularly as a part of R&M activity. Many of these tasks have been standardised by Scania and are called jobs. Jobs are carried out similarly by all workshops. The compensation for a particular job is set and so are the materials and the components which are needed. For Scania jobs mean less administration since the mechanic only needs to register the particular jobs that have been carried out. For customers jobs mean that the R&M is performed the same way independent of the location of the workshop.

3.6.3 Condition-Based Maintenance for vehicles[38] [39]

Most machinery failure is preceded by some sort of warning signal but in many cases the signal is not specific, thus giving little notice of individual distress before failure. However, Bloch and Geitner looking at process machinery, state that internal combustion engines often are quite viable to diagnose.

Often vehicles are serviced too early or too late since as the estimation of suitable intervals is very rough. Monitoring the condition of a vehicle and using the data collected for maintenance purposes have several advantages. These include:

- Saving money for the owner by reducing the cost for maintenance or additional wear.
- Fewer problems with operation disturbances as malfunctions are taken care of at an earlier stage.

Vehicle manufacturers have used more or less sophisticated types of CBM for several years. These systems, usually based on a combination of empirical data and complementing sensors, mainly monitor the condition of engine oil. However, other properties are also often considered for example break-pad wear. Figure 7 shows a schematic illustration of Volkswagen’s monitoring system. The input parameters to the left are compared to maps in the engine control unit and based on these the control unit calculates the residual distance to the next service.

[38] Kollman K, et al, *Extended oil drain intervals – conservation of resources or reduction of engine life*, 1998
[39] Bloch H.P, Geitner F.K, *Machinery failure and troubleshooting*, 1994, p 219-223

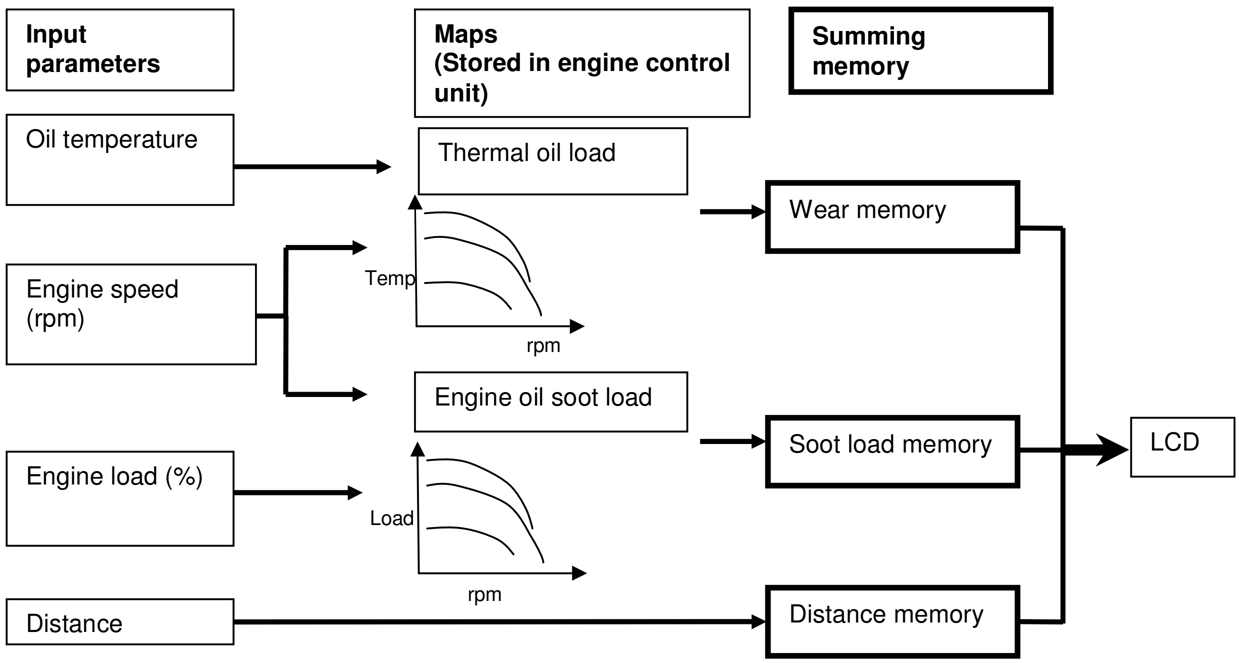


Figure 7. Design of a condition monitoring system[40]

3.6.4 Repair and maintenance contracts[41]

With an R&M-contract the customer pays an agreed price to cover repairs and maintenance for a certain period of time. What is included in the contract mainly depends on what the specific customer needs and thus the differences between contracts can be large. Certain parts of the vehicle can thus be excluded or included in the contract, all in accordance with customer needs. However, in a great majority of the cases a contract template is used with only minor alterations. The most popular R&M package in Sweden is called “Green Card” and includes breakdown service.

From the manufacturers point of view R&M-contracts have several advantages, the main one being that they tie the customer closer to the company. R&M is often an important part of the manufacturers turn-over. The profit margin on the vehicle itself is generally not that large and the major part of the profit is generated after the initial purchase has been done, on spare parts and services. Competition to offer the lowest possible life-cycle cost is tough within the heavy vehicle segment.

[40] Volkswagen AG, Self study program 224 Service Interval extension
[41] Sandström O, *What is repair and maintenance contracts*

Improved customer contact makes it possible to gain regular feed-back on product performance. This data can then be used for design and evaluation purposes. Also if the vehicle owner carries out maintenance and repairs in an authorized workshop the market for none-manufacturer parts narrows.

For the customers a suitable R&M-contract means the possibility to focus more on the actual transport task, their core business. Ultimately the overall cost is often lower and availability better, also the financial risk of expensive repairs is covered by the manufacturer. The price paid for an R&M-contract is dependent on the type of transport and the vehicle's specification. The length of the contract is fixed and the price can be either time or distance dependant.

3.6.5 Development of repair and maintenance

For manufacturers to provide a low total life-cycle cost and to attract profitable after sales business it is necessary to continuously develop the R&M services. However, to adapt the service program to the individual vehicle and perform necessary service only when needed is a complex process with several steps. Currently not enough is known about how operation conditions impact on the vehicle and CBM is not cost effective enough or even possible to use, in every situation. Gaining knowledge about the link between operation and wear on different subsystems is vital to design and to sell trucks with a highly competitive life-cycle cost.

3.7 Product lifecycle management (PLM) [42] [43] [44]

The aim of PLM is to provide stakeholders with comprehensive information regarding all the phases of a products lifespan. During the life of a product a large number of people are often involved in creating, selling, using and maintaining it but information about these different operations is often scattered and remains within the department that created it. A more integrated way of sharing knowledge across functional areas helps in the understanding of the whole lifecycle of a product and how different processes influence the product over a longer period of time. If for example maintenance data from vehicle workshops was available instantly for those working in the design department problems could be rectified faster. Firms have a lot to gain if they can learn from product malfunctions and implement this knowledge during product development, almost 80% of a product's final cost is determined at the design stage. Innovation and portfolio management, design, product data management, manufacturing planning, service management and support management are all essential contributors to PLM.

[42] Dutta D, *Creating a product lifecycle management development consortium,* 2003
[43] Fernandez F, *How PLM helps*, 2002
[44] eWeek, *PLM Aids product makers, buyers*, 2003

PLM is not a new tool but rather a set of different technologies linked together in a new way and from a new perspective. The concept of PLM can be compared to a big repository of data that distributes data to the right person at the correct time. Several companies deliver PLM systems but the user can adapt the system in accordance with their specific needs using software from several different suppliers. Certain standards have evolved that allow niche companies to develop software applications which are compatible with one or more core systems.

4 Vehicle information

This chapter describes the information that Scania can access about their own products, mainly after delivery to the customer has occurred, the characteristics and deficiencies that each of these sources have will be discussed.

4.1 Introduction

To what extent Scania will come in contact with a vehicle after it has been delivered to its final customer varies greatly. Not all owners will use Scania certified workshops for R&M activities. Perhaps they will only contact Scania or one of its subsidiaries if they have a warranty claim. Other vehicle owners will on the contrary chose to let Scania take care of all R&M hence making it possible for the organisation to retrieve information concerning specific vehicles.

All market activities within Scania generate a stream of information that can be used to understand how the vehicle performs and how it is operated. However, it is necessary to understand what characterises the data which is recorded and its deficiencies before it is used for evaluation purposes.

4.2 Chassis information

Once an order has been placed all information concerning the specification and delivery details for a vehicle is kept in a database and can be accessed simply by submitting the individual chassis number that each product is equipped with. Chassis information is often linked to other data sources providing background information about the vehicle and making it possible to search among similarly equipped ones.

4.3 Operation data

4.3.1 Introduction

One way to obtain knowledge about operation conditions is to ask the owner or the driver but the information they provide is subjective and commonly hard to quantify. In some cases it might be in the owner's interest to make it sound like the operation conditions are very favourable, for instance when buying a service contract. For example at one point in time about 90% of the construction vehicles Scania sold in Germany where classified as operation type 0, a group intended for vehicles operating under almost perfect conditions. Construction vehicles are commonly used for heavy transport on gravel roads with many stops and starts. It is highly unlikely that such a large part of them would qualify for operation type 0.

4.3.2 Description of operation data

Vehicle engines are becoming increasingly complex with electronic control systems monitoring and regulating many functions. The electronic control system optimises engine performance, driveability and efficiency in accordance with emission and design limitations. If anything which is monitored by the control system malfunctions during operation an error code is logged in the internal memory. When a vehicle comes in to the workshop data is extracted from the engine control system and the personal is hence notified if any malfunctions have occurred.

The engine control units that Scania uses do not only register errors and failures but also to some extent how the vehicle is operated. However, the unit only registers what happens not when it happens. Storing variables as a function of time would require a large amount of memory in the control unit.

The type of information, concerning operation conditions, which can be extracted from the vehicle, varies somewhat between different control units. Newly designed engine control units can store information about a greater number of variables thus giving a more complete picture of the operation conditions than what less recent models are able to.

The engine data used in this thesis is mainly based on the MS5 and MS6 control units, units that many vehicles are fitted with but these units are no longer produced. There are a few different models of MS5 and MS6, the main difference being that data is stored in different memory positions and that some information is subdivided in different ways. For example when the engine speed (revolutions per minute) is recorded the intervals are divided differently depending on the version of the control unit. The variables stored in the MS5 and MS6 engine control units which are possible to use for this project are the following:

- Cooling water temperature
- Vehicle speed
- Engine revolutions
- Matrix with engine load and engine speed

The matrix comes in two different versions containing either the total operation time or the total fuel consumption with a certain load and engine speed. These values can easily be transformed to percentage values. An example load and engine speed matrix can be seen in figure 8. In this particular figure load is presented as a value between 1 and 7. However, the underlying value of load is milligrams of fuel injected per cylinder and per stroke. A load of seven is equivalent to 210 milligrams of fuel or more per stroke.

	0-900	900-1200	1200-1400	1400-1600	1600-1800	1800-2000	2000-2500	2500- r/min
7		0.8 h						
6		39.2 h	227.2 h	712.8 h	163.8 h	38.5 h		
5	11.7 h	33.4 h	68.8 h	322.4 h	7.9 h	3.8 h	3.0 h	
4	22.5 h	35.5 h	86.3 h	875.6 h	7.5 h	2.2 h	0.7 h	
3	44.7 h	44.8 h	92.5 h	1044.9 h	8.3 h	3.1 h	0.7 h	
	1136.9 h	55.1 h	54.1 h	301.9 h	23.2 h	4.0 h	0.7 h	
2	15.9 h	8.3 h	14.3 h	84.6 h	5.1 h	1.2 h	0.2 h	
1	304.5 h	124.1 h	171.4 h	394.2 h	216.7 h	10.7 h	0.7 h	
0								

Figure 8. Load and engine speed matrix

Operation data recorded in MS5 and MS6 is available to the workshop through a tool called Scania Diagnos. The Scania Diagnos software contains a note saying that Scania would like the workshops to send operation data to a certain email address but it is not always done. Files which are sent to this address are incorporated in a separate database at Scania Technical Centre.

The gathering of operation data has been a slow process within Scania, a clear strategy is missing. The workshop have had to extract the data from the truck and mail the computer file to Scania but there have not been any real incentive for them to do so regularly. From time to time, for example when warranty claims have been exceptionally high Scania have asked the workshop to send them the operation data for evaluation purposes. Thus, it is uncertain if the operation data recorded is representative. Trucks in the database are to some extent problem vehicles.

When using operation data for evaluation purposes it must be considered that the data normally represents a mean value over a longer period of time. The memory that is used to store operation data is not reset when data is extracted. Thus, operation data reflects the whole life of the vehicle up until the time when the read out is made. During the span of its life a vehicle typically changes owner as well as transport task several times. It is hard to know what operation data reflects if the history of the truck is not known.

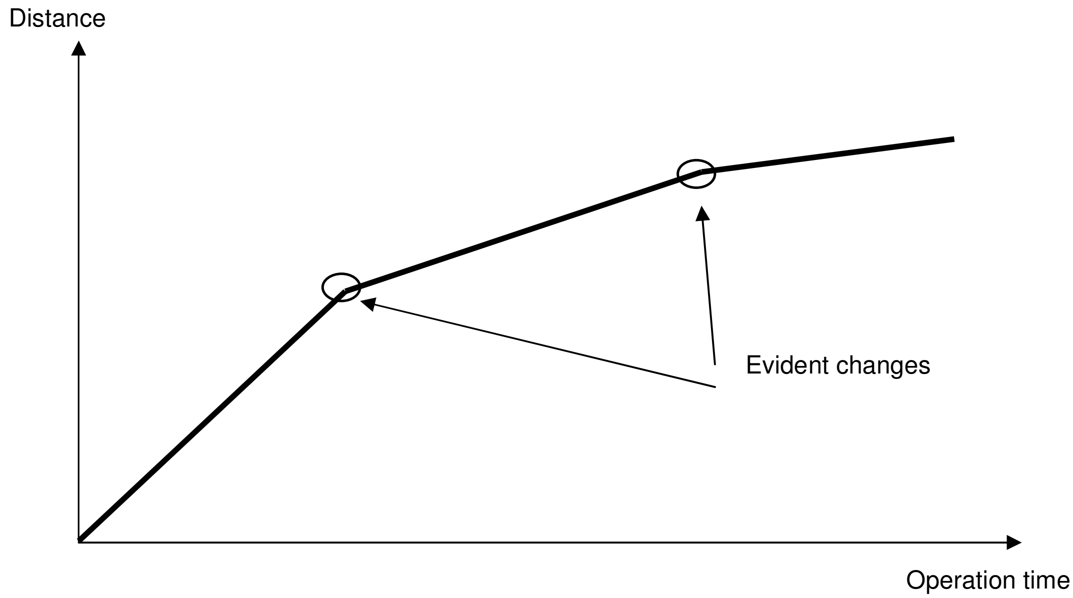


Figure 9. Aggregated distance as a function of operation time

4.3.3 Current use of operation data[45]

Operation data is to some extent used for evaluation purposes already. However, the use is not widespread and the application differs. In most cases the evaluation is made on a workshop level and the operation data is often discarded afterwards instead of sent to Scania to be incorporated in the existing database.

In Germany operation data is used for classification purposes and for decisions regarding oil-change intervals. The operation type classification within Scania today (table 1) was seen as to general and hard to use in practice. Furthermore it was also difficult to explain the system to customers.

45 Slany, O. *Einteilung der Ölwechselintervalle,* 2003

Scania Germany's workshops look at the estimated value for fuel consumption and the operation data matrix with load and engine speed when trying to decide on an appropriate operation type classification. The evaluation of operation data is based on that vehicles which consume a relatively large amount of fuel and are driven with a certain engine load needs to have a shorter oil change interval. The boundaries for acceptable fuel consumption and engine load are to a great extent based on experience. (The fuel consumption is automatically estimated from operation data when the diagnosis tool is connected in the workshop.) The method is mainly used to separate vehicles belonging to group zero from other groups and does not present a rigid framework. The workshop is left with a rather large amount of freedom to make the final decision.

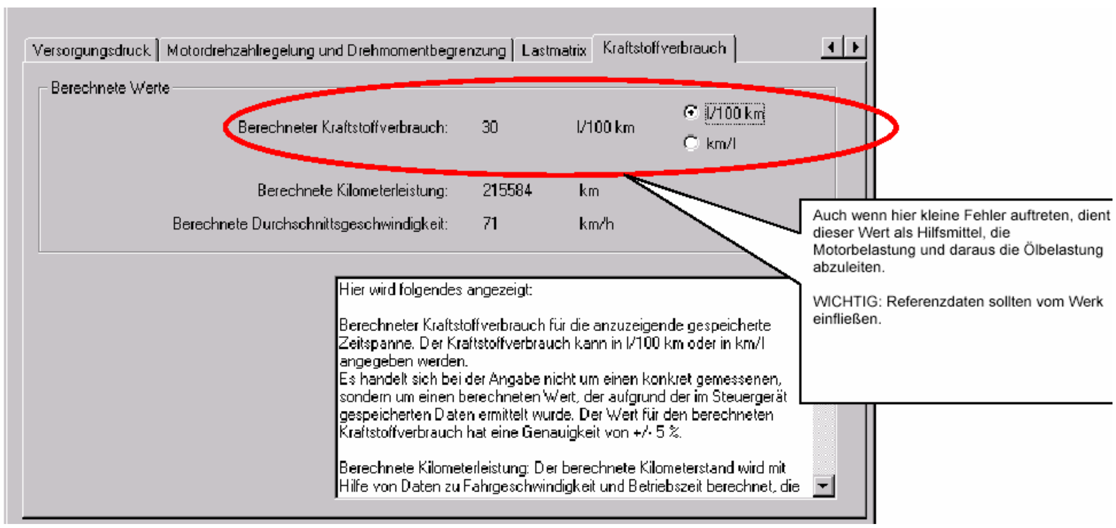


Figure 10. Calculated fuel consumption

4.3.4 Improvement of operation data[46]

Present and future Scania vehicles have an engine control system which differs significantly from the MS5 and MS6 units used in this project. More sensors and the ability to record many more variables make it possible to gain additional understanding concerning vehicle operation conditions.

Among the additional variables which can be recorded in more recent control units is a load factor, an estimation of GTW. The load factor can vary greatly depending on the type of cargo that is being transported. Often trucks are driven entirely without load half the distance. The strain on components such as the engine and suspension is strongly related to the load factor. Thus, it is a fair assumption to

[46] Goebelbecker P.E, Ferrone C, *Utilizing electronic control module data in accident reconstruction, 2000*

believe that the GTW is connected to vehicle wear and the need for repair and maintenance. Monitoring GTW might give vital clues when establishing a link between operation conditions and their effects on the vehicle.

Some manufacturers use systems which can log for example the maximum speed ever recorded, maximum engine speed ever recorded, number of hard break incidents, number of engine over speeds, brake switch status, clutch switch status and throttle position. Combined with certain electronic modules which continuously store information concerning the last period of operation this can be used for example to investigate accidents. However, using operation data to analyse collisions is still rather controversial and not widely used. The systems have many times not been evaluated carefully enough and it is uncertain how trustworthy they are.

As the possibility to register operation information develops new ways to utilise it will open up. However, to take full advantage of operation data it is necessary to have a clear strategy for collecting and storing the material. There are many technical solutions that can simplify or even eliminate the problems which are now associated with registering operation data. Fleet management systems which track each vehicle and record their whereabouts can for example easily be equipped with functions which continuously update operation information.

4.4 Scania Assistance

Scania Assistance is service function operating 24-hrs and 365-days a year helping customers with technical problems or breakdowns. The assistance network works together with a comprehensive network of workshops and covers most areas in Europe. As soon as the driver experience any kind of problem it is possible to call the assistance centre and ask for help, most of the times the driver will be able to speak his native tongue with the operator. After the phone call Scania Assistance takes control of the situation and coordinate the appropriate actions e.g. repair crew, replacement vehicle, accommodation, taxi, police or ambulance. Depending on what sort of agreement the vehicle owner has got Scania Assistance can also guarantee payment to the workshop and thus make sure that the vehicle is back on the road as soon as possible.

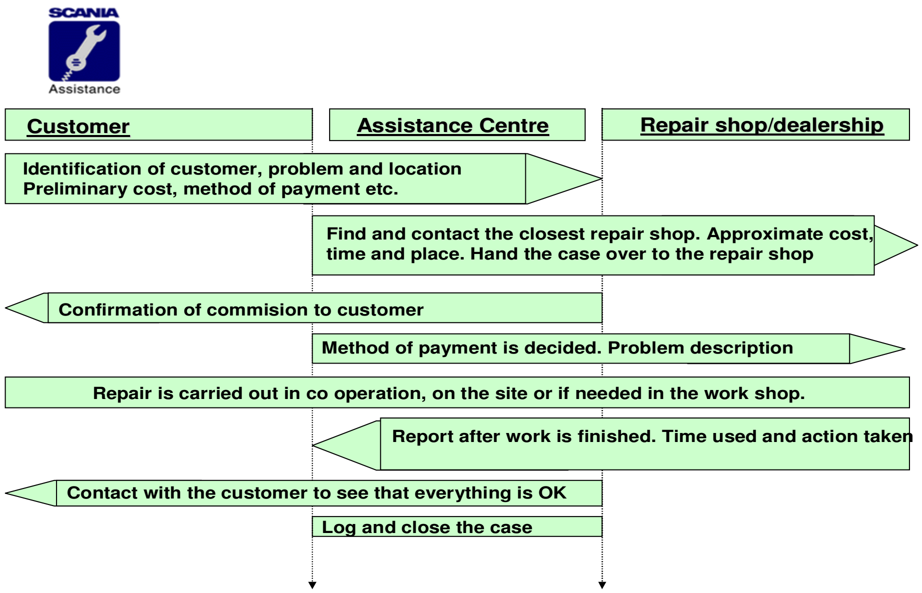


Figure 11. Scania Assistance flow chart[47]

Scania Assistance logs data concerning all cases they receive, in total about 500 each day. Both the driver's description of the error and later the mechanics diagnosis and actions are kept on record for future reference. Operators can always access a vehicle's previous assistance history, something that can simplify the handling of a new case. The records from Scania Assistance are used for statistic evaluation of quality on vehicles and different subsystems. However, in many cases the driver will call to the workshop immediately and the incident will then not be reported to Scania Assistance. Only in Great Britain, where certain procedures have been established in such cases, will Scania Assistance always be notified. Thus, the data from Scania Assistance will not fully reflect the frequency of breakdowns even among vehicles using the service, except for in Great Britain.

[47] http://138.106.100.11/eba/ 2004-02-26

4.5 Warranty data

All vehicles sold by Scania are covered by warranty during the first year of operation. Should anything fail during that time, which is not caused by abnormal use, it is repaired free of charge by Scania. The repairs are carried out by Scania and its subsidiaries and the information concerning the repair is kept on record in a separate database. Parts exchanged and the failing part, as judged by the workshop, is logged. Since it is in every customer's best interest to report errors which occur during the time when the vehicle is covered by warranty the warranty data ought to be a very reliable source of information. Using warranty data it is possible to calculate the overall failure rate of specific components, at least during the first year of operation.

Some errors happen more or less at random while others might have a clear course of event and develop over time. Problems caused by wear are likely to depend more on the number of kilometres driven and the number of operating hours than the actual time factor itself. Since warranty data only covers the first year of operation the statistics might look rather different than what they would have done if the same type of records where kept over time. There is a risk that problems which occur during this time are mainly caused by quality problems.

4.6 Repair and maintenance data

In those cases where a customer chooses to buy a R&M contract the vehicle will be maintained and repaired by Scania or one of its appointed representatives. Slightly depending on in which country the R&M is carried out the workshop will typically store data concerning the specific contract. Financial information as well as information concerning what measures that have been taken and which parts that have been exchanged is recorded. How this information is stored differ somewhat between countries. In Sweden Scania has built a database called RAMAS where this information can be accessed and analysed using numerous perspectives and filters. An example of data available in RAMAS can be seen in figure 12. In most countries except Sweden it is not yet possible to look at the data on such a detailed level, but similar systems will be implemented in due time.

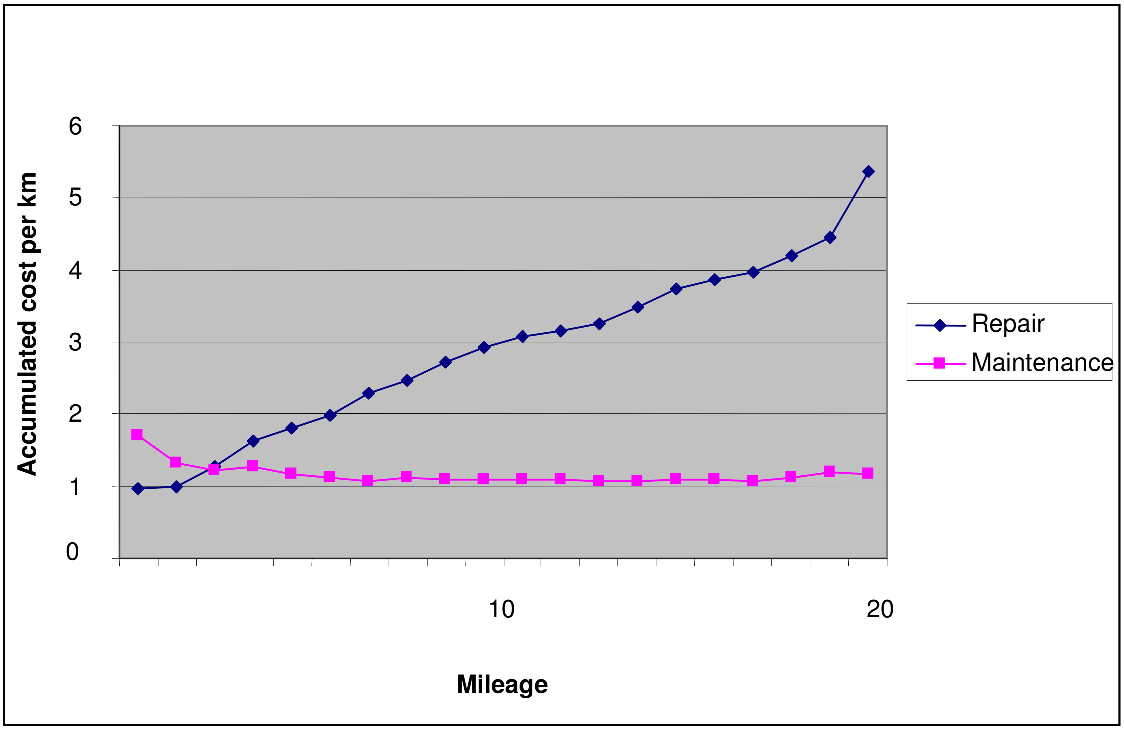


Figure 12. Example of data available from RAMAS showing the aggregated cost per kilometre (data has been normalized)

The R&M statistics are developed to support the market organisation, especially the contract and service businesses. Hence, an important aspect of the RAMAS database is to be useable for analysis of R&M profitability and pricing. RAMAS is also designed to serve as a flexible platform for statistical analysis and is full of verified historical data from different business systems.

The total number of vehicles on contract for Scania Sweden amounts to slightly less than three thousand, a fairly small number of the total sales. Nonetheless, it ought to be more than enough to investigate the link between operation factors and vehicle wear. Trucks with an R&M contract are a good source of information since their records are continuously updated during the entire length of the contract, usually about four or even five years of operation.

4.7 Fragments of data

To compare data from two or more of the available information sources can be a challenge. Operation data has only been recorded in the database for a very small percentage of all vehicles. It is only warranty data and chassis data that are available for all vehicles. A comparison of R&M information with operation data must start with extraction and recording of operation data from a sample of vehicles. To locate specific vehicles and extract information concerning operation conditions can be highly time consuming.

4.8 Which data to analyse

R&M data is the only source of information concerning repairs that covers a longer period of time. Scania stores data concerning the specific contract and uses it to evaluate different aspects of the R&M business. To use R&M data and operation data is the most suitable when trying to establish a link between operation conditions and wear. However, in the initial part of the project there was no accessible operation data from any of the contract vehicles and it was therefore decided that an initial analysis would be made using warranty information. Warranty data covers all vehicles during the first one or two years of operation making it possible to use trucks already registered in the operation database.

Information from Scania assistance might be used as a complement to other data but not by itself. Nothing is known about service and repair that is carried out on the truck during the rest of the time. It can also be the case that the driver calls straight to the closest workshop when a problem occurs and actions taken will then not be registered by Scania assistance.

5 Analysis - Warranty

In this chapter data is analysed to investigate if any viable connection between operation data and the need for repair and maintenance activity can be found in warranty data. If such a connection exists, how can it be described?

5.1 Introduction

It was decided that, at least initially, the analysis would focus on data that was already available. Gathering additional data from vehicles was time consuming and during that time an analysis of operation data using warranty information was deemed suitable. Many important insights might be gained which could then be applied when data from R&M vehicles had been collected.

5.2 Sample - warranty

For the initial analysis vehicles located in Great Britain were chosen. There were several reasons for this but the main one was that the basic warranty covered two years in Great Britain compared to one year in most other countries. Since problems which arise due to operation conditions can be expected to develop over time it is important to have information which does not only cover the initial part of vehicle operation. Vehicles from Great Britain were also among the most frequent in the operation database. In Great Britain all problems which cause an unexpected stop are taken care of by a Scania workshop and are reported to Scania Assistance.

Numerous different factors affect the vehicle but only a few of these can be accurately measured and recorded in the MS6 and MS5 units. If the result of the analysis is to be correct, it is important to block factors which influence the outcome and which we cannot control. In order to do this, to the largest possible extent, the vehicles used in the initial sample all had similar specifications. The rear axle ratio was considered to be especially important since it directly influences engine speed, an important parameter in operation data. Engine size, chassis and wheel configuration were also evaluated. The sample had to represent a large quantity of vehicles sold by Scania. Trucks designed for long-haulage equipped with a 12-liter engine were predominantly used. Selecting trucks which operated, mainly, in Great Britain was a way to exclude differences in operation conditions based on geographic location. All vehicles in the sample were manufactured year 1 or later. The vehicles included in the sample are listed in appendix 1.

5.3 Information retrieved concerning the sample - warranty

The two matrixes containing the percentage of the total operation time and percentage of total fuel consumption occurred with a certain load and engine speed was retrieved for the sample population. Even if vehicle speed and cooling water temperature would have been possible to use they were found unsuitable for evaluation purposes. It is simply not possible to differ between vehicles using these values since the intervals used in the operation data memory are too rough, making the data look almost identical for most vehicles.

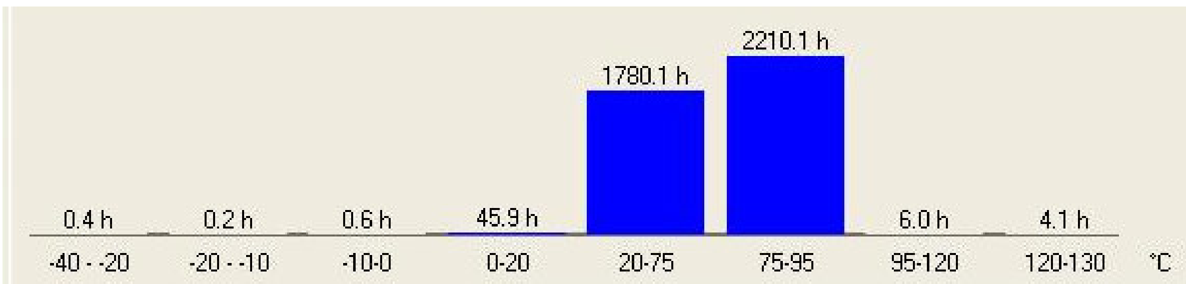


Figure 13. Cooling water temperature extracted from operation data

Information concerning all warranty claims was retrieved for the vehicles in the sample population. For all but two vehicles the warranty time was two years, the two exceptions had a three year warranty. In some cases data warranty claims are recorded even after the end of the time covered by the basic warranty. Extended warranty due to known quality problems or good-will is the reason for that.

5.4 Preparing data for analysis – warranty

A spread sheet similar to what can be seen in table 3 containing warranty and repair data was prepared. The spread sheet also contained a brief description of why the part was being replaced for each entry. All in all the warranty data retrieved constituted almost 10.000 entries; all the parts that had been replaced during the warranty period.

Table 3. Example of warranty information retrieved

CHASSI_NO	DEL_DAT	REP_DAT	Days_to_Repair	1000km	PART_NO	PART_DESC	GRP	COST_£
XXXXXXX	1999-07-01	1999-07-07	6	XXXX	1396911	MAT	18	XXXX
XXXXXXX	1999-07-01	2000-01-19	202	XXXX	9002571	RAB2571R COMBI	16	XXXX
XXXXXXX	1999-07-01	2000-01-27	210	XXXX	562810	MAINT.KIT(S9,12	97	XXXX
XXXXXXX	1999-07-01	2000-03-14	257	XXXX	1109992	INSTR.HOUS	17	XXXX
XXXXXXX	1999-07-01	2000-03-14	257	XXXX	1358793	BALL JOINT	13	XXXX
XXXXXXX	1999-07-01	2000-05-10	314	XXXX	1602180	BATTERY 180AH W	16	XXXX
XXXXXXX	1999-07-01	2000-07-07	372	XXXX	564546	MAINTENANC	97	XXXX
XXXXXXX	1999-07-01	2000-07-07	372	XXXX	1423018	DOOR HANDL	18	XXXX
XXXXXXX	1999-07-01	2000-07-07	372	XXXX	1337003	UNKNOWN PT.NO.	40	XXXX
XXXXXXX	1999-07-01	2000-12-01	519	XXXX	562810	MAINT.KIT(S9,12	97	XXXX
XXXXXXX	1999-07-01	2000-12-01	519	XXXX	1387155	LENS	16	XXXX
XXXXXXX	1999-07-01	2000-12-22	540	XXXX	551572	SLAVE CYLINDER	4	XXXX

Operation data only concern the engine and the drive train. Warranty data on the other hand covered every part on the vehicle which had been replaced. Before an analysis was performed it was thus necessary to remove entries from warranty information which did not have any connection to the engine or the drive train and was not affected by the operation conditions. People working within the area of field quality gave advice concerning which type of entries to keep and which type of entries to remove. Nevertheless, it was still in some cases difficult to decide if a removal was justified or not, since there was such a great diversity of situations described in the warranty records. Another problem with warranty data was that several parts were often replaced on the same occasion. If they are all used to resolve one problem or multiple ones was not always easy to know.

The current speedometer reading is recorded for most warranty claims but not always correctly. For example it is common that workshop employees remove a few zeroes in the report writing 1000 of kilometres instead of kilometres. To avoid this problem from affecting the analysis speedometer readings were controlled for deviations and obvious errors. In a few cases when no proper odometer reading could be found trucks were eliminated from the analysis.
The total number of warranty data entries was summed up for each vehicle and divided by the last speedometer reading available in the warranty data. The result was a frequency stating the number of operation dependent errors per thousand kilometres.

The load/engine speed matrix is an 8x8 matrix, thus containing sixty-four values. However, it is not the single values which are interesting but mainly the overall pattern of the operation time between different engine speeds and loads. Comparison of single values is not meaningful since the value itself seldom is of any major significance. Looking at the total distribution of operation time gives a much better understanding for how the vehicle is used.

For comparison purposes it was deemed suitable to divide the matrix into a few larger areas and calculate new values; constituted of the sum of the original cells within the newly formed area. It was expected that high engine speed and high loads would cause increased wear and thus increase the number of power train and drive train related errors. However, exactly how to divide the matrix to discover such a pattern was not obvious and several alternatives were tried, an example can be seen in figure 14.

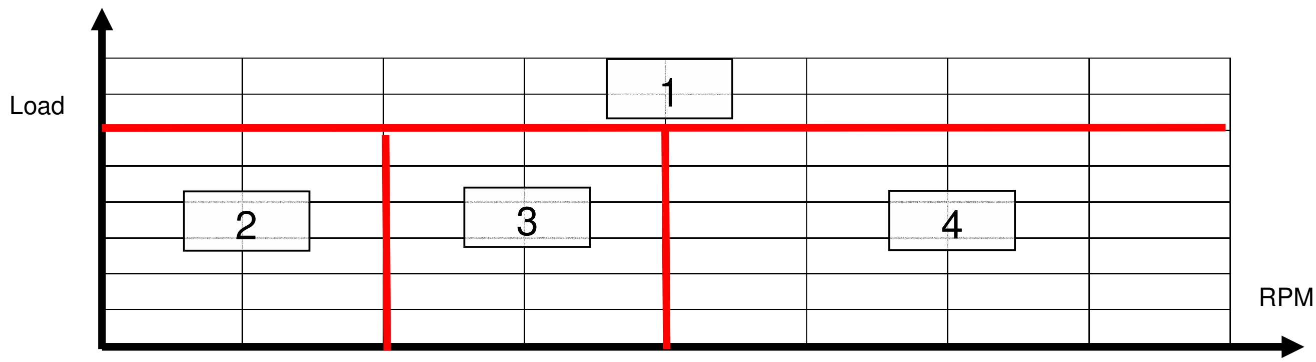


Figure 14. Example of how the matrix was divided into larger areas

5.5 Scatter plots - warranty

5.5.1 Operation time matrix

The correlation between the amount of operation time in a certain area of the matrix and the calculated error frequency per 1000 kilometres, for the sample vehicles from Great Britain, were analysed visually using scatter plots. One such scatter plot can be seen in figure 15. To discover any trend or pattern in the plots was hard and once the correlation coefficients were calculated they indicated that the correlation was indeed weak or even zero. However, dependency measures must always be interpreted with great care since it is hard to describe the dependency with a single numeric value. The major part of the sample was located in a rather narrow interval, when looking at the distribution of operation time in the load/engine speed matrix. Hence, a few outliers could influence the value of the correlation coefficient greatly.

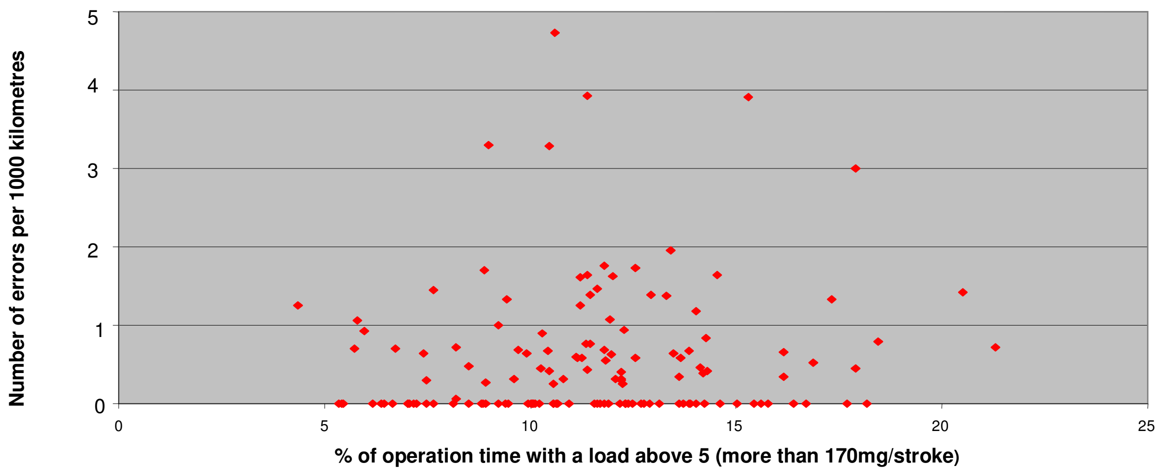


Figure 15. Error frequency as a function of operation time (data has been normalized)

In order to simplify the plots and increase the possibility to discover patterns that might exist the values along the x-axis were divided into intervals. For all the vehicles within a certain interval the mean value of the error frequency was calculated and the result was a less complicated plot. The plot in figure 16 is the equivalent of that in figure 15 but contain only the mean values. Neither in the plots containing mean values could any significant trends be found. However, the mean values which are located below ten percent and above twenty percent on the x-axis are based on few observations and are thus sensitive to influence from single vehicles. Additional observations in these areas could thus change the appearance of the plots to some extent.

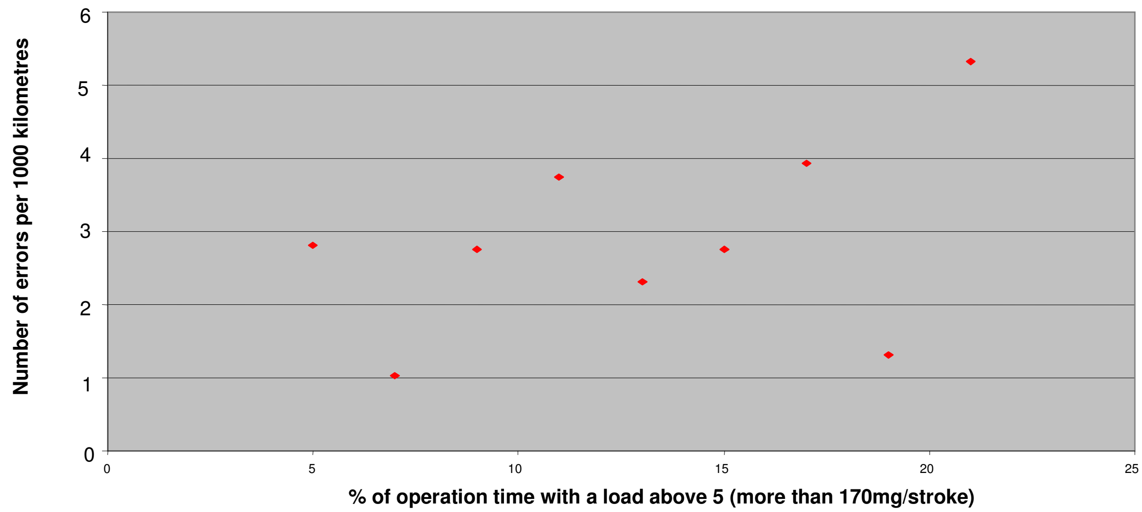


Figure 16. Mean values of error frequency as a function of operation time (data has been normalized)

To avoid too much influence from one or a few vehicles a new calculation of mean values was made with ten vehicles in each interval. With a majority of the trucks in a rather narrow area the plots did not have an even distribution of points along the x-axis. An example of such a plot can be seen in figure 17.

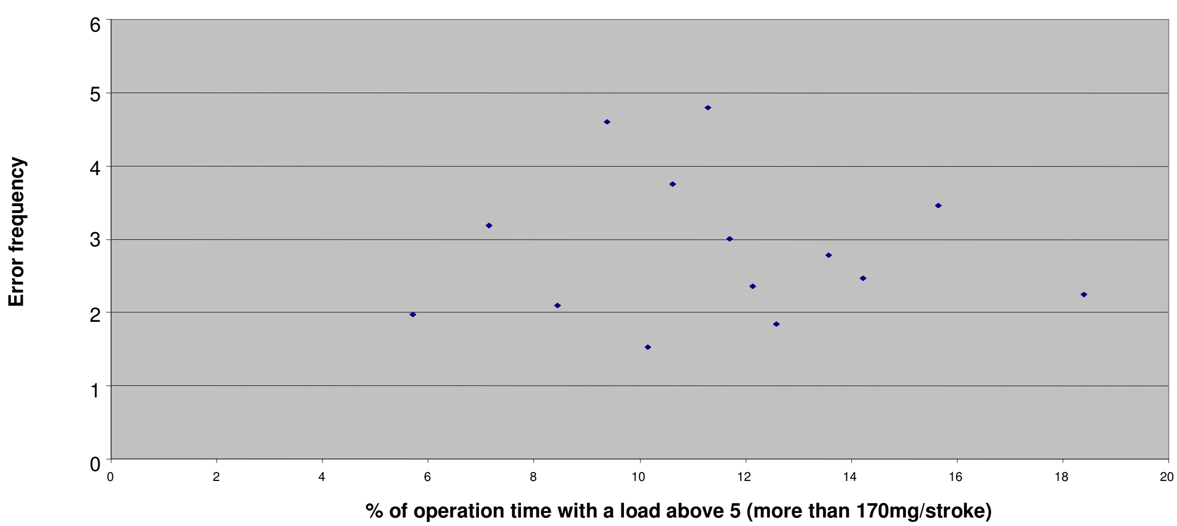


Figure 17. Mean values of error frequency as a function of operation time (data has been normalized)

5.5.2 Fuel consumption matrix

Trucks which operate under tough conditions are likely to have somewhat higher fuel consumption than what is normal for other similar vehicles. Thus, fuel consumption might be used as an indicator of how severe the operation conditions are. To investigate this relationship the fuel consumption for each of the vehicles was plotted against the error frequency per 1000 kilometres. The value of the fuel consumption was calculated as an index value and could only be used for comparison between vehicles.

Fuel consumption index = $\Sigma_{ij}(\theta \times \omega \times \Omega \times \text{Percentage value})$

θ = Mean value mg/stroke in interval
ω = Mean engine speed in interval
Ω = (Number of cylinders)/2
i = The number of rows in the matrix
j = The number of columns in the matrix

If for example the percentage value of the matrix cell representing 90-130mg/stroke at engine speeds between 1200 and 1400 rpm is 17 for a six cylinder engine that cell will add to the index in the following way.

Fuel consumption index = …… +……. + (110 x 1300 x 3 x 17) +…….

A plot of this data can be seen in figure 18 and it is evident that there is no clear correlation between the fuel consumption index and the calculated error frequency per 1000 kilometres.

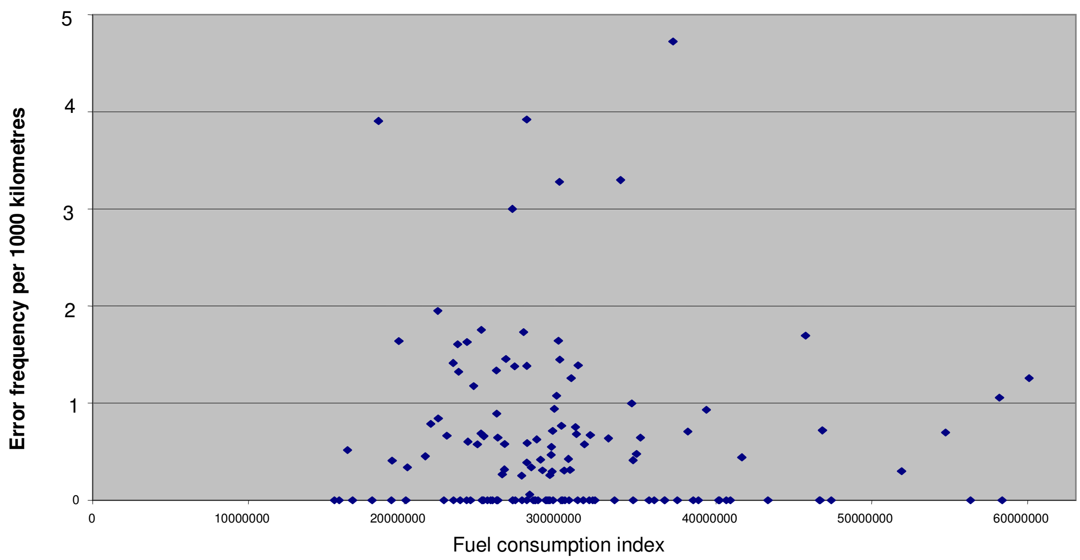


Figure 18. Error frequency as a function of fuel consumption index (data has been normalized)

5.6 Result - warranty

No clear link between operation factors and the origin of vehicle problems has been established in the analysis. In all of the evaluated cases the correlation was indeed weak. Thus, the changes in power-train related warranty claims can not be explained by differences in operation data.

5.7 Discussion – warranty

The overall error frequency is not a linear function. Problems which arise because of quality deficiencies will appear at random and be most frequent during the initial part of the operation period. Operation dependant errors on the other hand will increase in frequency over time as the trucks are exposed to the prevailing operation conditions. Thus, as the number of errors due to poor quality gradually starts to decrease the operation caused problems will increase in frequency. Problems that are caused by certain operation conditions and arise early on are hard to discover since they become almost invisible among more frequent quality errors

6 Analysis – R&M

In this chapter data is analysed to investigate if any viable connection between operation data and the need for repair and maintenance activity can be found in R&M data. If such a connection exists, how can it be described?

6.1 Introduction – R&M

In the second part of the analysis, where R&M information was used, it was assumed that the distribution of errors looks somewhat like the illustration in figure 19. During the initial period of operation quality problems will be much more frequent than operation caused errors. However, after some time the number of quality caused errors will level off and occurring problems will increasingly become a consequence of wear and the prevailing operation conditions. Excluding the early part of vehicle operation thus makes it possible to avoid influence from errors which are caused by evident quality deficiencies when trying to establish a link between operation factors and vehicle wear. Differences between trucks in the distribution of errors after this initial period are caused mainly by operation conditions. The frequency of operation caused errors increases over time for the same vehicle.

Problems which are caused by quality deficiencies are very hard to predict and cannot be effectively prevented with maintenance activity. Final product quality is greatly influenced during the construction phase and as the development process proceeds it becomes substantially more expensive to rectify problems which occur. Communicating product performance to the development organisation is essential in order to improve quality levels.

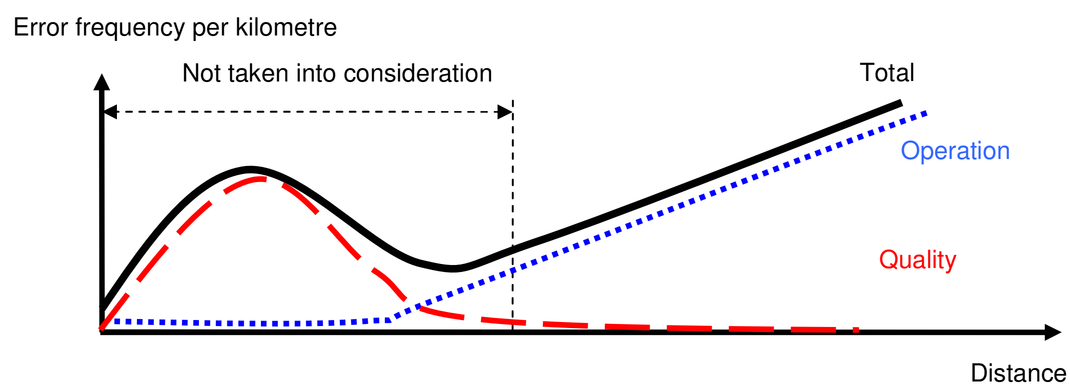


Figure 19. Error frequency as a function of operation time

6.2 Sample – R&M

In parallel with this particular project there was another one carried out within the R&M area, aiming to identify operation related cost drivers. About one hundred vehicles with maintenance contracts, all typical long haulage trucks registered in Sweden were evaluated. Information about each vehicle, its operation environment, its operation conditions, and its driver were retrieved during phone interviews with the registered owners (table 4). The collected material was statistically analysed by the controlling and quality information function (RSE) within Scania.

Table 4. Information retrieved during the interviews

Vehicle	Chassis number
	Body
	Trailer
Environment	Region
	Topography
	Road conditions
	Speed profile
Operation	Profile
	Gross Train Weight (GTW)
	% of distance with maximum GTW
	Fuel consumption
	Kilometres per year
Driver	Does the driver own the truck?
	Number of different drivers
	How is responsible for maintenance?
	Has the driver had any special training?

Since the two projects to some extent complemented each other it was deemed suitable to evaluate operation data from the engine control unit for the same set of vehicles. The vehicles included in the sample are listed in appendix 1

The collection of operation data from the engine required involvement from several local workshops. Once the dealership responsible for a specific R&M contract had been identified a letter was sent out asking for their assistance (a copy of the letter can be seen in appendix 2). Preferably on the next planned workshop visit the operation data was to be extracted from the engine control unit and sent to Scania for evaluation.

After five weeks operation data from about twenty vehicles had been received. Information from these trucks could not be directly compared since they did not constitute a uniform sample but needed to be divided into subgroups. This meant that the maximum sample size which could be used was in fact about ten vehicles, not enough for a proper evaluation. However, the time plan for the project made it impossible to wait any longer. A proper analysis of the collected operation data has to be done after the completion of the project. Thus, the analysis of R&M data would not be as extensive as initially planned; only the information collected during interviews with vehicle owners could be utilised. Since a cornerstone of the project was to evaluate the connection between operation data and wear it was decided that the stated fuel consumption would be used as a reflection of operation data.

6.3 Preparing the analysis

6.3.1 The RAMAS database

The database which has been set up to contain information concerning vehicles with R&M contract, RAMAS, is mainly used by the after sales organisation. To identify a specific truck these functions simply uses the contract number and that method is used also in the RAMAS database. However, the remaining Scania organisation uses the chassis number for identification purposes. Incorporating chassis number in the database was possible but would slow it down and affect some of the functions in a negative way. In order to avoid this, each of the chassis numbers were matched with a specific contract number which could then be used while performing searches in the database. As contract numbers and chassis numbers were compared six trucks were found which had more than one R&M contract connected to them. To evaluate R&M information from these vehicles would be difficult and they were hence excluded from the analysis.

6.3.2 Information retrieved from RAMAS

As a measurement of error frequency it was deemed suitable to use the number of jobs carried out on the vehicle. Jobs is only one of several measurements available in RAMAS which also contain information about the number of visits to the workshop, number of hours spent in the workshop as well as financial reports. However, it was decided to use jobs as a measurement since it is the best reflection of the error frequency. If the number of hours or the incurred cost were to be used for comparison certain time consuming and expensive malfunctions might affect the outcome of the analysis greatly. A job is simply a set of actions which are performed to resolve a problem of some kind and is registered the same way no matter how extensive it is, thus all errors will be equally weighted. The number of errors is assumed to be greatly dependant on the distance travelled rather than elapsed time. For comparison the number of jobs carried out per kilometre was calculated and broken down into subgroups, an example of this can be seen in figure 20 which displays the average number of jobs per 100.000 kilometres on subgroup engine for all contract vehicles.

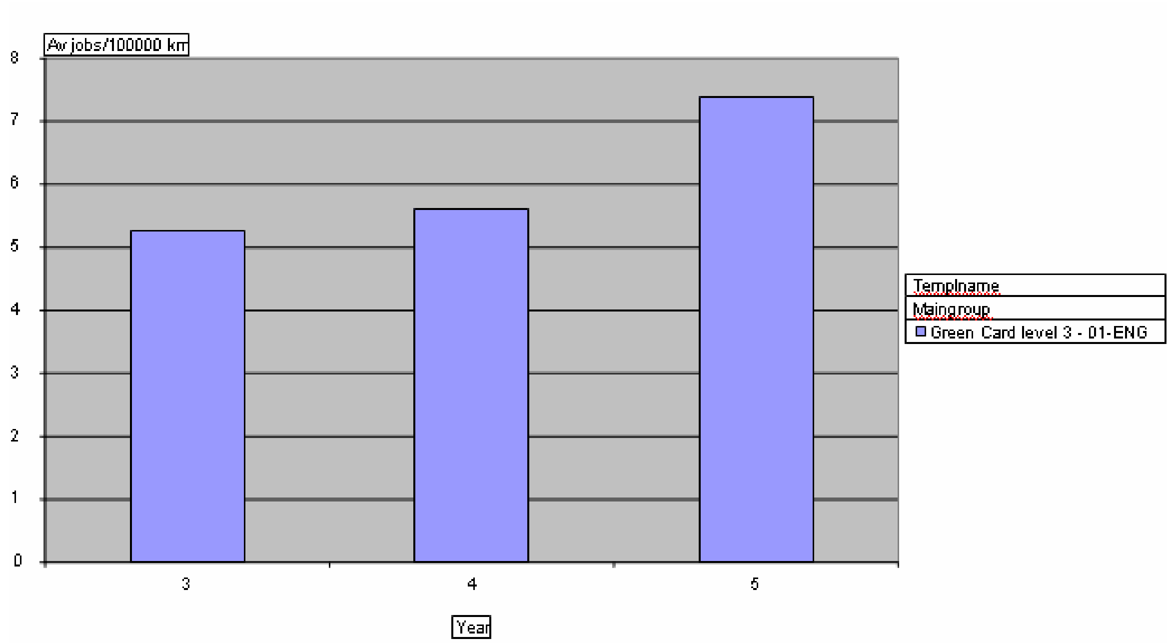


Figure 20. Average number of jobs (normalized value) per 100.000 kilometres and operation year carried out on subgroup engine (n=2500)

Repairs which were carried out during the initial two years of operation have not been considered since they are assumed to be affected greatly by quality issues. In addition information in RAMAS concerning this period of time is very often incomplete and should be evaluated with great care. Any malfunctions which occur during the initial year are treated as warranty issues and thus not registered in the RAMAS database.

From year three and on the number of jobs carried out per vehicle increases with the distance travelled. This is the starting point of the model in figure 19 and can also be seen in figure 21 which displays the number of jobs carried out on the main subgroups of the power train and drive train per vehicle and operation year. The total number of jobs per operation year does not increase as much as does the number of jobs per 100.000km. Vehicles that are a few years old are not used as much as when they were new. Figure 22 illustrates the average number of jobs per vehicle and operation year.

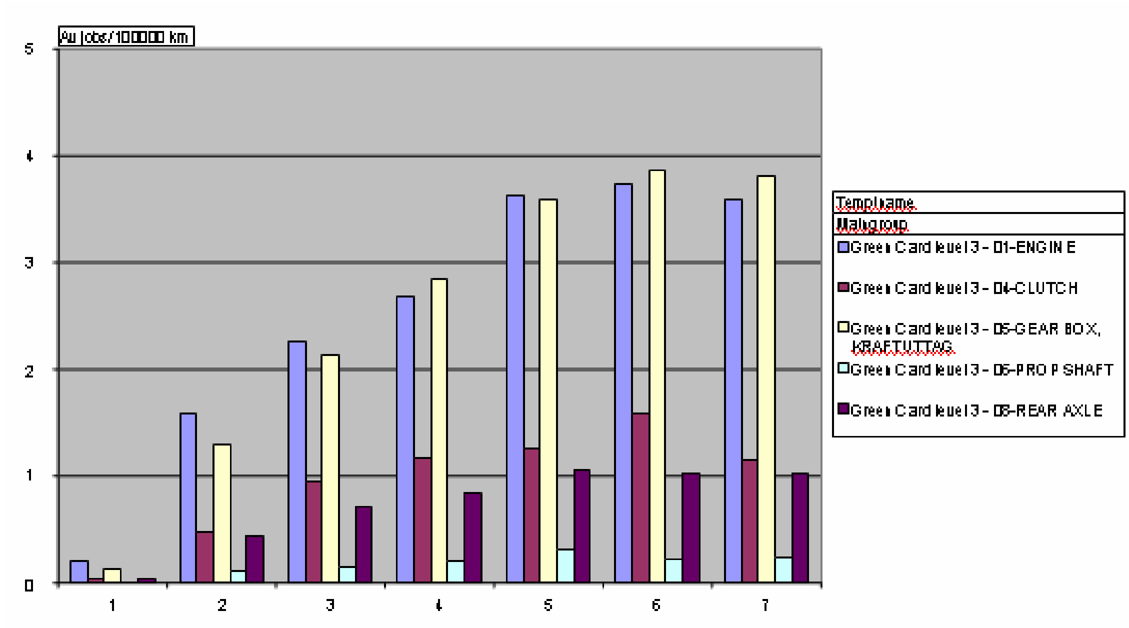


Figure 21. Average number of jobs per 100.000km (normalized value) each operation year divided into subgroups of the power train and drive train for all vehicles in the RAMAS database (n=2500)

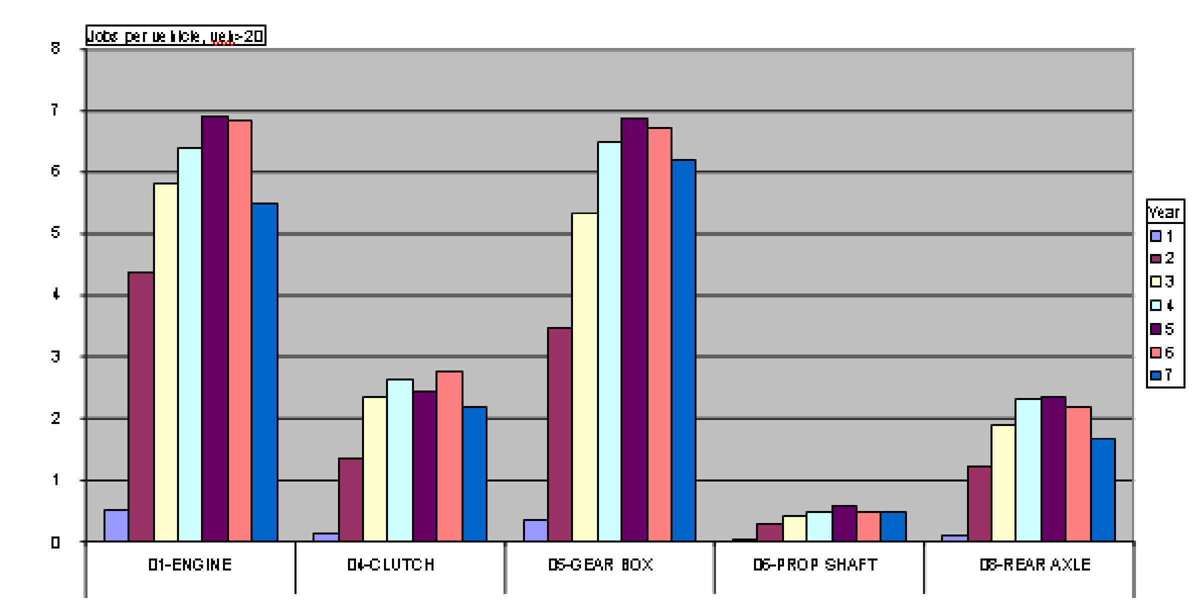


Figure 22. Average number of jobs per vehicle(normalized value) each operation year divided into subgroups of the power train and drive train for all vehicles in the RAMAS database (n=2500)

A majority of the vehicles in the sample were manufactured year 1 or 2 but also trucks of more recent date were included. Nonetheless, only a few vehicles have been operated for more than four years some only three years. For comparison it was decided that data from operation year three until operation year five would be used. The mean number of jobs per 10.000 kilometres and operation year was calculated for all vehicles in the sample

6.3.3 Comparison between the sample and the larger collective

Before an analysis of the gathered material was carried out the vehicles in the samples were compared to the overall population in the RAMAS database. This was done to see if the sample was representative for the majority of the trucks with an R&M contract. Any findings in the analysis would of course be more significant if they applied to a great part of the total vehicle fleet.

Looking at the aggregated number of jobs carried out per vehicle as a function of mileage (see figure 23 and 24) it is clear that the vehicles in the sample correspond to the overall population of trucks in the R&M database. However, there are rather large differences in the aggregated number of jobs depending on when the truck was manufactured. Since the introduction of the 4-series there has been a significant decline in the aggregated number of jobs each model year.

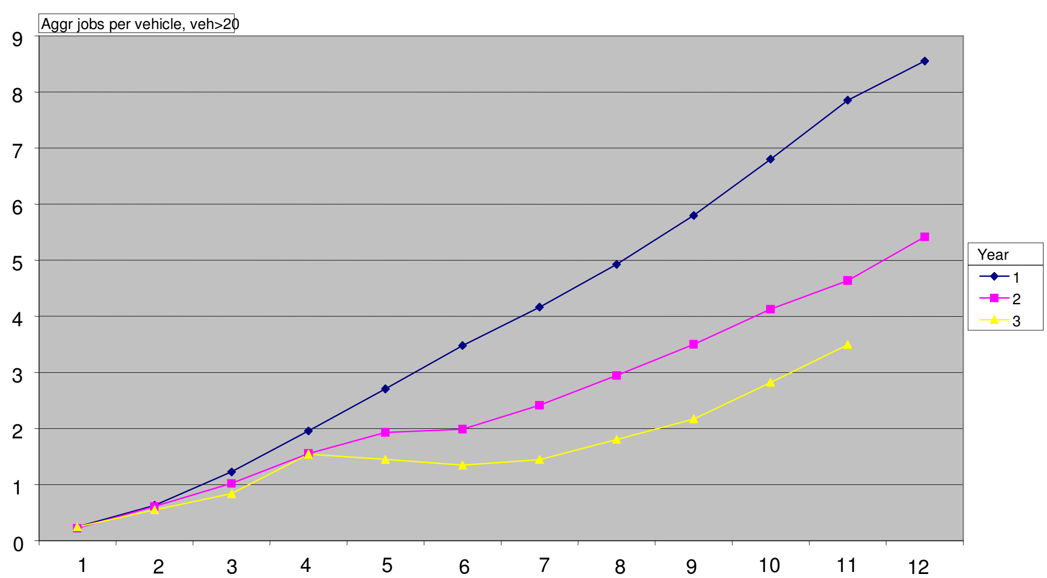


Figure 23. Aggregated number of jobs per vehicle as a function of mileage (both values are normalized) for all R&M contract vehicles manufactured year 1, 2 and 3 (n=1400)

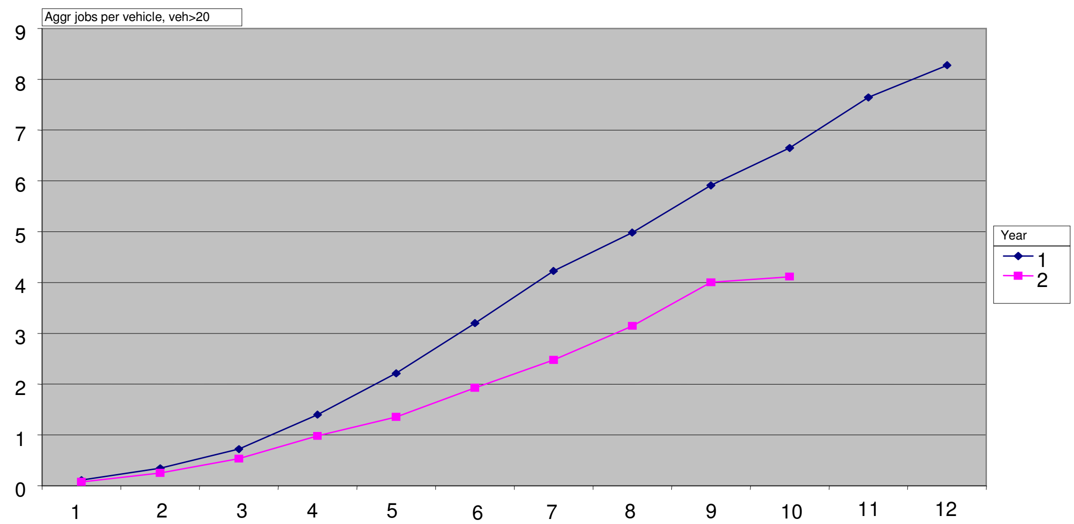


Figure 24. Aggregated number of jobs per vehicle as a function of mileage (both values are normalized) for vehicles in sample manufactured year 1 and 2 (n=65)

The similarity which was found between vehicles in the sample and overall fleet is valid also when focusing on subsystems. In figure 25 and 26 the aggregated number of jobs per vehicle on the engine is shown for the entire population of vehicles and the sample population.

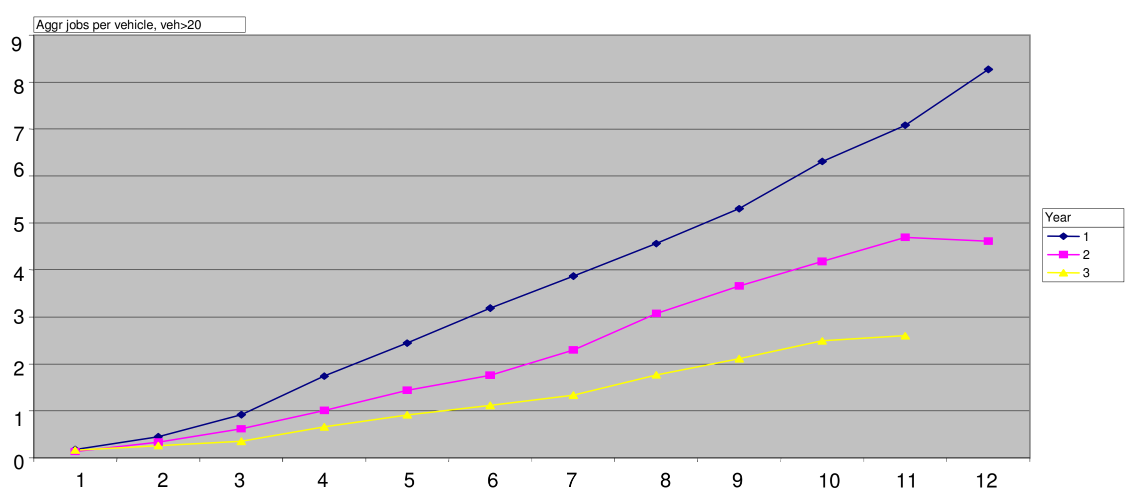


Figure 25. Aggregated number of jobs per vehicle as a function of mileage on engine components (both values are normalized) for all R&M contract vehicles manufactured year 1, 2 and 3 (n=1400)

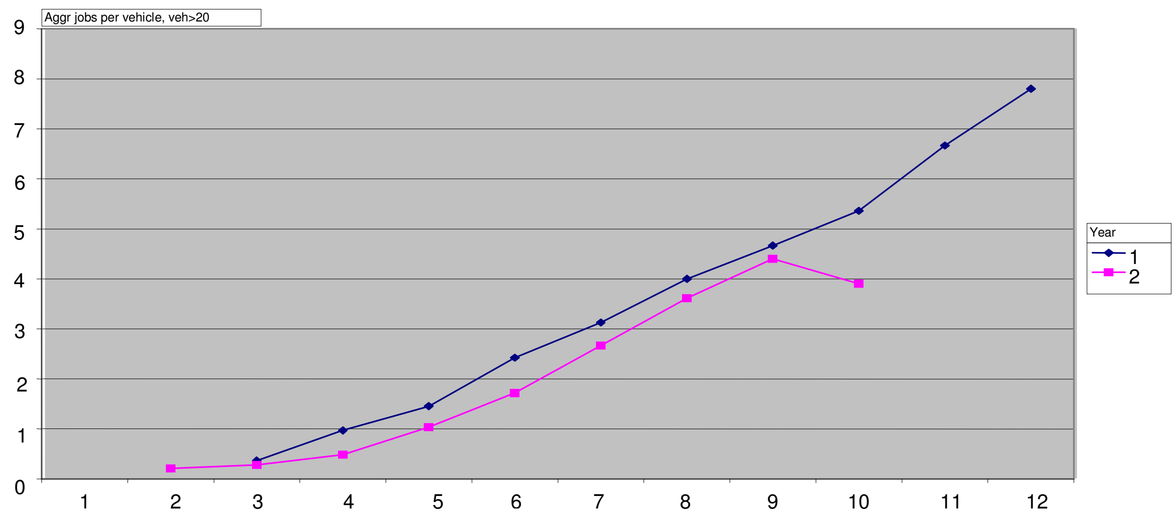


Figure 26. Aggregated number of jobs per vehicle on engine components as a function of mileage (both values are normalized) for vehicles in sample manufactured year 1 and 2 (n=65)

6.4 Scatter plots - R&M

6.4.1 Stated fuel consumption

A comparison between the number of jobs carried out on the power train and drive train per kilometre and the, by the owners, stated fuel consumption was done to provide input for the analysis of operation data from vehicles. The fuel consumption is directly related to the amount of torque delivered by the engine and hence a measurement of the forces which affect the components of the drive train and power train.

Initially when the stated fuel consumption was plotted against the number of jobs carried out on the power train and drive train it was not possible to see any trend. However, being aware of the great difference in number of jobs performed between specific model years (see figure 22) it seemed likely that the specification was important. A closer look at the information in RAMAS made it obvious that the number of jobs performed on a vehicle was influenced by the engine size. Figure 27 illustrates the aggregated number of jobs during mileage for vehicles with engine 1 and 2.respectively. Hence, an analysis of the connection between fuel consumption and wear had to be based on vehicles manufactured during the same period and with similar specifications.

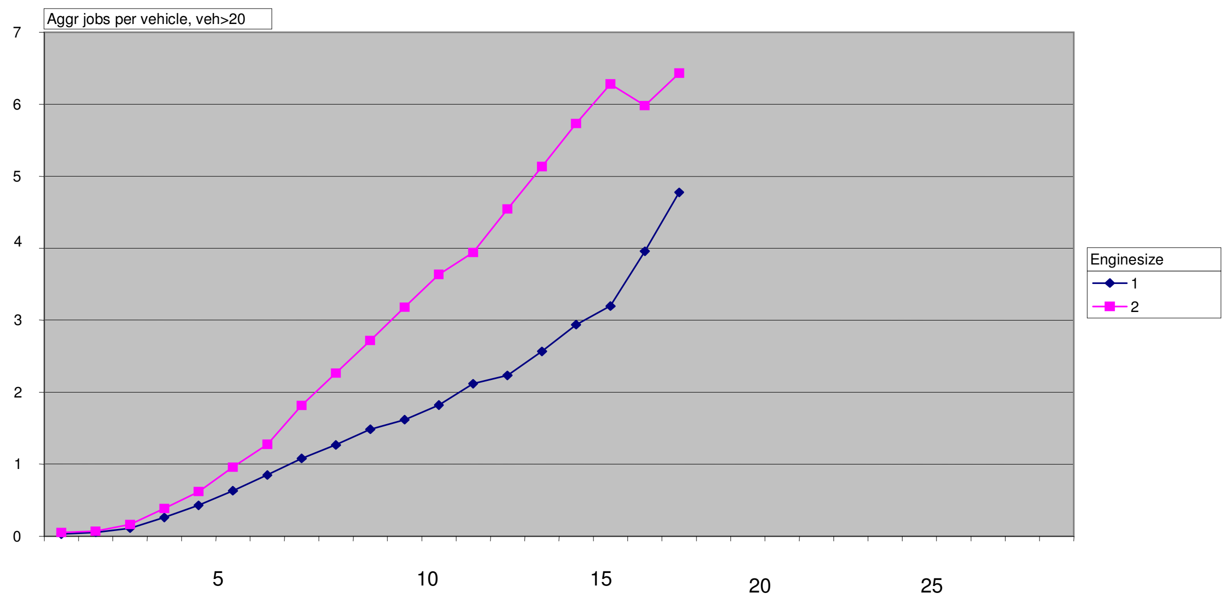
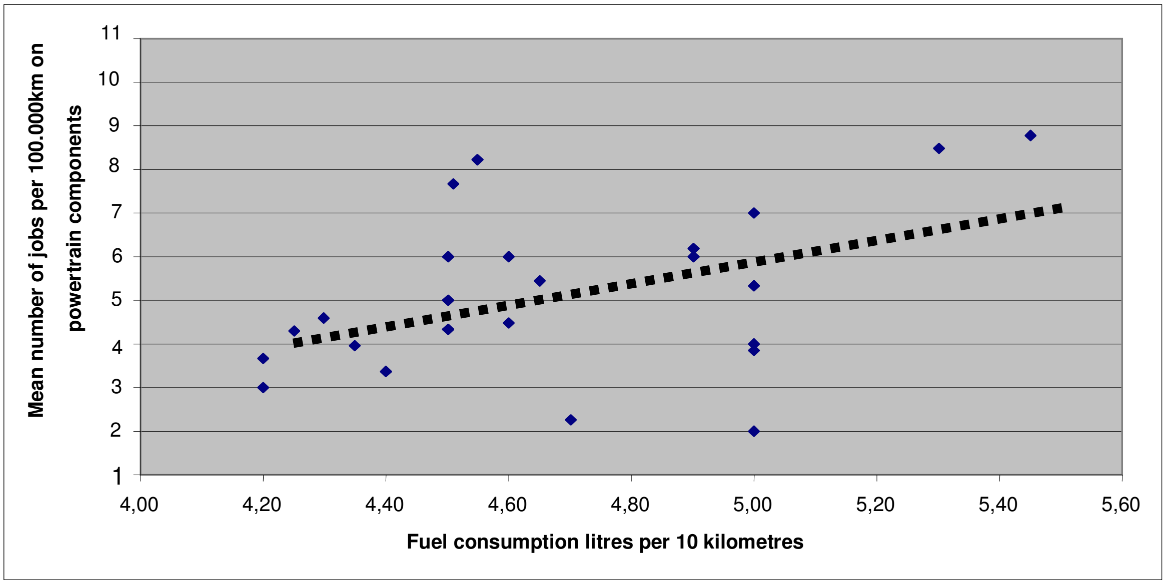


Figure 27. Aggregated jobs per vehicle as a function of mileage (both values are normalized) for engine type 1 and 2 (n=700)

Before the analysis was resumed it was decided that jobs performed on the drive train were to be separated from those performed on the power train. The main reason was a suspicion that the power train was not as susceptible to torque as the drive train. The scatter plot in figure 28 shows the relationship between fuel consumption and number of jobs per 100.000 kilometres performed on the drive train for vehicles manufactured year 1 and equipped with an engine of size 2. In figure 29 the number of jobs per 100.000 on the drive train has been replaced with a similar figure concerning the power train instead. The correlation coefficient between fuel consumption and the number of jobs per 100.000 kilometres performed on the drive train was calculated to 0,45.



Figur 28 Mean number of jobs per 100.000 kilometres (normalized value) on all drive train components as a function of fuel consumption (n=24)

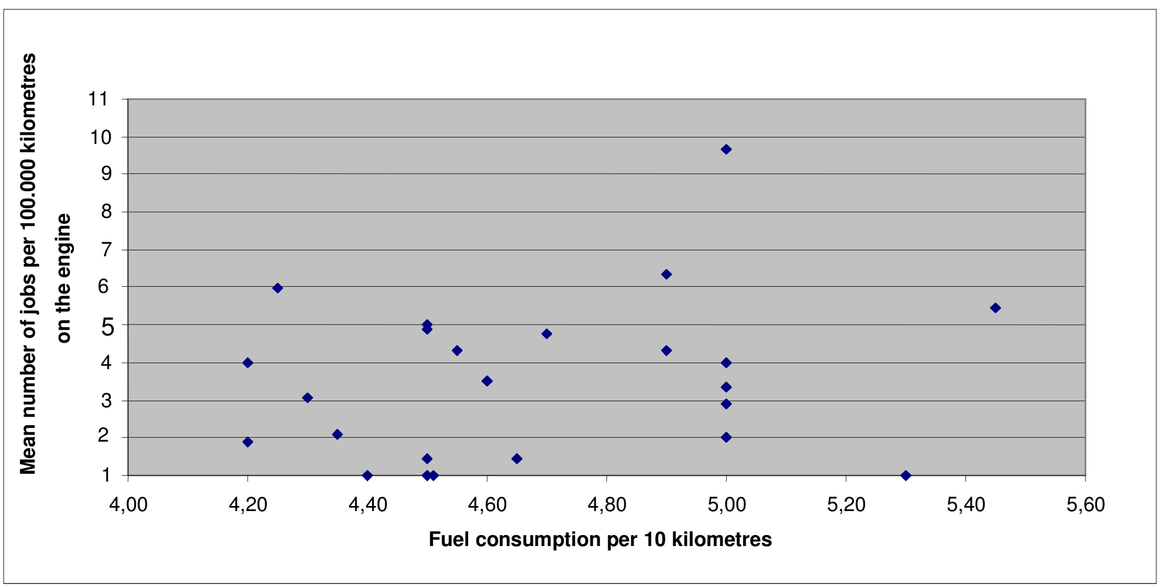


Figure 29 Mean number of jobs per 100.000 kilometres (normalized value) on engine components as a function of fuel consumption(n=24)

To investigate the relationship between fuel consumption and jobs performed on the engine itself further the engine was divided into specific subgroups. After an assessment of the different sub components of the engine it was decided that jobs on the the air intake, the protection covers and the engine suspension would not be taken into consideration since they were not exposed to wear caused by operation conditions which could be registered in the operation data memory. However, this change had very little effect on the overall data. The number of jobs performed on the eliminated components was small and concerned only a handful of vehicles. To compare the number of jobs per kilometre with the fuel consumption for each subgroup of the engine was not possible. Most vehicles had only had jobs performed on one or two of the engine components and the sample quickly became too small when focusing on single areas.

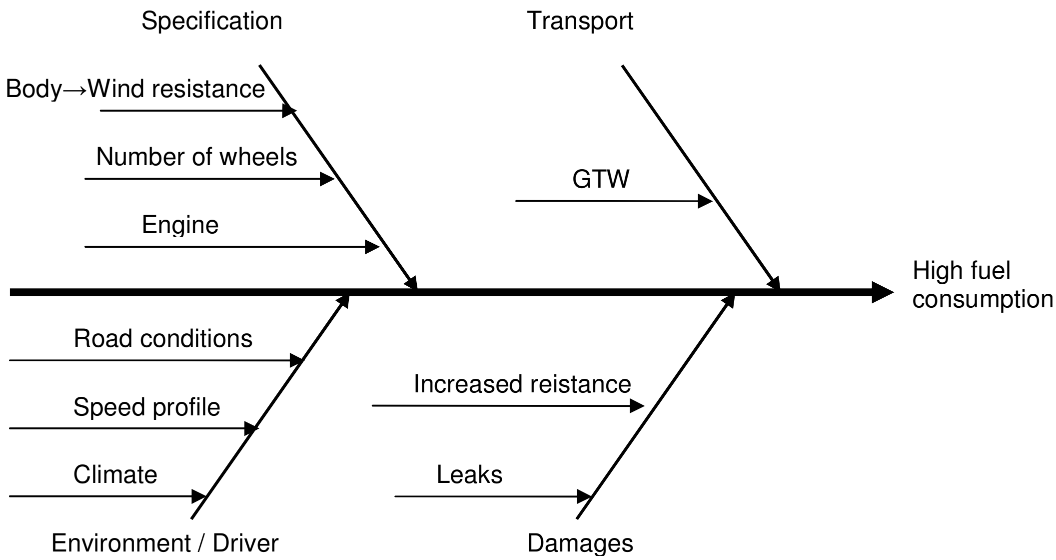
6.5 Result

The number of jobs performed on the vehicle per 100.000 kilometres will increase with operation time. However, there are significant differences depending on when the vehicle was manufactured and also to some extent its specification. These differences in number of jobs per 100.000 kilometres must be taken into consideration when data is evaluated. Comparisons should primarily be made between similar vehicles.

There seem to be a relationship between fuel consumption and the number of jobs carried out on drive train components. This connection has not yet been verified since suitable data is not available. The shortage of data also makes it hard to perform a more thorough investigation; the sample quickly becomes too small.

6.6 Discussion

Fuel consumption is only one of several factors which might be used as an indication of operation conditions. Thus, the relationship between fuel consumption and jobs performed on the power train and drive train can never be linear. First of all there is always an element of chance involved when a malfunction occurs. There are also several conditions that might cause damage but do not have any effect on fuel consumption. If for example the drive train or the power train is exposed to sudden extreme conditions this might lead to a malfunction but not influence the fuel consumption. Furthermore, there are many parameters that affect fuel consumption and not all of them will influence wear in a similar way. An example of a cause-and-effect diagram for high fuel consumption can be seen in figure 30.



Figur 30. Cause-and-effect diagram for high fuel consumption

7 Conclusions and recommendations

7.1 Conclusions

The link between vehicle operation conditions and wear is highly complex. A great number of factors influence the vehicle to some extent but to quantify the importance of each factor is difficult since they interact with each other. Only a minor part of these variables can be measured and recorded. To eliminate the influence of certain factors that are not monitored is hard and hence it is not an easy task to investigate the relationship between a single operation factor and vehicle wear. Factors beyond control might conceal patterns that are present.

Knowledge about operation conditions and how they influence the vehicle is crucial in a market where services are increasingly important. Margins on the truck itself are under constant pressure and innovative services are a way for manufacturers to stay ahead of competition. Being able to adapt R&M activities, to individual customer needs can hence create major benefits for a company. The ability to move towards condition based maintenance rather than preventive maintenance will minimise vehicle down time, improve customer satisfaction and make it possible to more accurately predict the cost incurred by a certain vehicle.

When investigating patterns of vehicle wear it is important to use data which covers a longer period of operation time. Problems and errors which are caused by operation conditions will develop over time. Most of the repairs which are done during the initial period of operation are caused by quality deficiencies. Over time as the number of quality errors start to diminish and the number of operation caused errors will steadily increase. The only source of information available which can provide data regarding all R&M activities even after the initial operation time is RAMAS which contains extensive records about all vehicles which are covered by an R&M contract in Sweden.

The overall fuel consumption is a reflection of operation data and a direct measurement of the torque delivered by the engine. That a high level of torque will influence the components in the drive train and increase wear seems reasonable and a likely connection has also been shown between fuel consumption and the mean number of jobs carried out on the drive train per kilometre. However, the engine itself does not seem to be susceptible to torque in the same way as the drive train.

Still jobs performed on the power train are not less frequent than jobs performed on the drive train. This can partially be explained by the fact that the engine is much more complex than most part of the drive train, except for the gearbox which has a similar frequency of jobs per 100.000 kilometres. Yet, it seems unlikely that engine malfunctions would not to some extent be an effect of the prevailing operation conditions.

For classification purposes it might be valuable to use a measurement of vehicle fuel consumption but its connection to wear on the drive train must first be verified.

An estimation of fuel consumption is easily calculated from operation data and such a function is present in Scania Diagnos already. Thus, it would be rather simple to start using fuel consumption as a parameter for classification. However, fuel consumption is in itself not enough for a proper grouping and needs to be combined with other variables. The mean error frequency for a vehicle differs significantly depending on specification and manufacturing year.

The amount of information presently available is not sufficient to make a proper investigation and evaluation of operation data's usefulness. The problem is that the various types of vehicle information are only registered and saved occasionally. The different types of information systems needs to be better integrated.

7.2 Recommendations for further work

To gain a more profound understanding of how operation conditions influence wear it is important to investigate the fundamental mechanisms which are involved. What initiates damage to the engine components and what causes the damage to propagate? Once the causes of wear and failure have been properly analysed it will be easier to understand the impact that certain operation factors might have. In the long-term operation factors that are regarded to be especially interesting should, if possible, be recorded as a part of operation data.

To be able to investigate and evaluate operation data a strategy for the gathering of such data has to be developed. Presently operation data is collected by individual departments when a specific need for information arises and the amount is often very limited. The use of operation data for evaluation of operation conditions for Scania vehicles in general makes it necessary to record information more systematically. Furthermore the collection of operation data needs to be better coordinated with the recording of other types of information, preferably R&M information. The amount of operation data needs to be rather extensive since vehicles which do not have the same specification and manufacturing year are not easily comparable.

The operation data that is presently being collected must be properly evaluated. Fuel consumption figures used in the analysis were based on statements by the owners and not actual data from the vehicle. Once operation data from this initial sample has been collected it would be suitable to control the accuracy of these figures. In some cases where the owners have not provided any information concerning fuel consumption operation data could be used for this purpose. However, a second set of data would be valuable since the link between fuel consumption and wear on the drive train ought to be properly verified. The second data set should, just as the first one, consist of typical long haulage trucks with similar specifications. Since manufacturing period will influence the number of jobs carried out per kilometre greatly it would be an advantage if trucks are manufactured during the same period.

When evaluating the influence of operation data RAMAS or a similar database would serve as a useful tool. The idea is to incorporate operation information in the same system as R&M data. This way it would be possible to compare a number of vehicles and investigate the influence that certain operation conditions have on the R&M activity. Hence, it could be easier to identify the most influential operation factors and cost drivers which might be used for classification purposes.

A new classification system based on measurable operation factors will not be static. If significant differences in R&M activity are found to be dependent on certain operation conditions these differences ought to be eliminated. The solution can be to adapt maintenance more to the prevailing operation conditions; create new operation classes or perhaps sub classes. One other solution would be to develop new varieties of certain components which are then engineered to handle specific conditions but have a uniform maintenance interval. Ultimately future choice is likely to be a combination of these efforts. R&M will be more condition based but this is only possible to a certain extent. To develop certain kinds of performance steps and hence adjust the vehicle specification to suit customer needs better is likely to be as important.

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Electronic resources

http://138.106.100.11/eba/ *2004-02-26*

Appendix 1

Information concerning the warranty data sample

2+2 R&M Great Britain

Conditions Chassis

Chassis No	140 GB chassis from file	
Assembly Period	(1999033-2002022)	MOUNT_PER
Delivery Date	(19990331-20020301)	DEL_DAT

Conditions 2+2 Data

Data from	2003-10-08
ChassisNo	From CHASSI_NO

Explanation

Flag 1	M	3+3 R&M
Flag 1	P	2+2 R&M, paid £75 for MOT. Doesn't pay £10 inspections.
Flag 1	Q	2+2 R&M in all Europé
Flag 1	R	2+2 R&M
Flag 2	A	Additional warranty on certain components

9 chassis hasn't been in used 2 years (730 days) yet
Campaign and EPS (Extended Production Support) is included

CHASSI_NO	MOUNT_PER	DEL_DAT	DEL_DAT from 2+2 file	Flag 1	Flag 2
XXXXXXX	1999033	1999-03-31		R	
XXXXXXX	1999041	1999-05-06		R	
XXXXXXX	1999042	1999-04-27		R	
XXXXXXX	1999042	1999-05-07		R	
XXXXXXX	1999042	1999-05-07		R	
XXXXXXX	1999044	1999-05-17		R	
XXXXXXX	1999044	1999-06-03		R	
XXXXXXX	1999044	1999-06-03		R	
XXXXXXX	1999052	1999-05-24		R	
XXXXXXX	1999052	1999-07-10		R	
XXXXXXX	1999052	1999-07-10		R	
XXXXXXX	1999052	1999-07-10		R	
XXXXXXX	1999052	1999-07-10		R	
XXXXXXX	1999052	1999-07-10		R	
XXXXXXX	1999052	1999-06-01		R	
XXXXXXX	1999054	1999-07-30		R	

XXXXXXX	1999054	1999-07-30		R	
XXXXXXX	1999054	1999-07-30		R	
XXXXXXX	1999054	1999-06-11		P	
XXXXXXX	1999061	1999-07-01		R	
XXXXXXX	1999063	1999-07-12		P	
XXXXXXX	1999063	1999-07-05		P	
XXXXXXX	1999074	1999-09-01	1999-09-01 00:00	R	
XXXXXXX	1999081	1999-09-03		R	
XXXXXXX	1999084	1999-09-10		R	
XXXXXXX	1999084	1999-09-17	1999-09-17 00:00	R	
XXXXXXX	1999084	1999-09-17	1999-09-17 00:00	R	
XXXXXXX	1999091	1999-10-01		R	
XXXXXXX	1999092	1999-09-30		R	
XXXXXXX	1999092	1999-10-04		P	
XXXXXXX	1999094	1999-12-03	1999-12-03 00:00	R	
XXXXXXX	1999103	1999-11-01		P	A
XXXXXXX	1999104	1999-12-13		R	
XXXXXXX	1999104	1999-12-13		R	
XXXXXXX	1999104	1999-12-13		R	
XXXXXXX	1999104	1999-12-31		R	
XXXXXXX	1999104	1999-11-16		R	
XXXXXXX	1999104	1999-12-01	1999-12-01 00:00	R	
XXXXXXX	1999104	1999-10-26		R	
XXXXXXX	1999111	1999-11-16		R	
XXXXXXX	1999112	1999-12-08		R	
XXXXXXX	1999112	1999-12-01	1999-12-01 00:00	R	
XXXXXXX	1999113	1999-12-30		R	
XXXXXXX	1999114	1999-12-09		P	
XXXXXXX	1999122	1999-12-20		R	
XXXXXXX	1999122	1999-12-30		R	
XXXXXXX	1999122	1999-12-22		R	
XXXXXXX	1999123	1999-12-28		R	
XXXXXXX	1999123	1999-12-28		R	
XXXXXXX	1999124	2000-01-11		P	
XXXXXXX	2000011	2000-01-24		R	
XXXXXXX	2000014	2000-03-14		R	
XXXXXXX	2000022	2000-03-01		R	
XXXXXXX	2000022	2000-03-02		Q	
XXXXXXX	2000022	2000-03-02		Q	
XXXXXXX	2000022	2000-03-02		Q	
XXXXXXX	2000023	2000-03-01		P	
XXXXXXX	2000023	2000-03-02		R	
XXXXXXX	2000024	2000-03-06		R	
XXXXXXX	2000031	2000-04-13		R	
XXXXXXX	2000031	2000-03-14		R	
XXXXXXX	2000031	2000-03-21		R	
XXXXXXX	2000033	2000-04-01		R	
XXXXXXX	2000041	2000-04-01		R	

XXXXXXX	2000043	2000-05-01	R	
XXXXXXX	2000044	2000-05-10	R	
XXXXXXX	2000052	2000-06-06	R	
XXXXXXX	2000053	2000-06-06	R	
XXXXXXX	2000061	2000-08-17	R	
XXXXXXX	2000061	2000-08-10	R	
XXXXXXX	2000061	2000-08-17	R	
XXXXXXX	2000061	2000-08-10	R	
XXXXXXX	2000062	2000-07-01	R	
XXXXXXX	2000064	2000-07-01	Q	
XXXXXXX	2000064	2000-07-17	R	
XXXXXXX	2000073	2000-08-01	R	
XXXXXXX	2000073	2000-08-01	R	
XXXXXXX	2000073	2000-09-01	R	
XXXXXXX	2000074	2000-09-01	R	
XXXXXXX	2000074	2000-09-01	P	
XXXXXXX	2000083	2000-09-17	R	
XXXXXXX	2000091	2000-10-02	M	A
XXXXXXX	2000092	2000-10-01	R	
XXXXXXX	2000092	2000-10-19	P	
XXXXXXX	2000092	2000-10-03	P	
XXXXXXX	2000092	2000-10-03	P	
XXXXXXX	2000092	2000-10-12	P	
XXXXXXX	2000093	2000-09-25	P	
XXXXXXX	2000093	2000-10-17	P	
XXXXXXX	2000093	2000-10-19	P	
XXXXXXX	2000093	2000-10-19	P	
XXXXXXX	2000093	2000-10-12	P	
XXXXXXX	2000093	2000-09-27	R	
XXXXXXX	2000093	2000-09-26	M	A
XXXXXXX	2000094	2000-10-10	R	
XXXXXXX	2000094	2000-10-17	R	
XXXXXXX	2000094	2000-09-26	P	
XXXXXXX	2000094	2000-10-01	R	
XXXXXXX	2000094	2000-10-01	R	
XXXXXXX	2000103	2001-01-01	R	
XXXXXXX	2000103	2000-11-01	P	
XXXXXXX	2000103	2000-11-02	R	
XXXXXXX	2000104	2000-11-22	R	
XXXXXXX	2000104	2000-11-10	R	
XXXXXXX	2000104	2000-11-22	R	
XXXXXXX	2000104	2000-11-10	R	
XXXXXXX	2000111	2001-01-17	R	
XXXXXXX	2000112	2001-03-01	P	
XXXXXXX	2000113	2001-01-01	R	
XXXXXXX	2000113	2000-11-24	Q	
XXXXXXX	2000114	2000-12-24	R	
XXXXXXX	2000122	2001-01-05	R	

XXXXXXX	2000124	2001-01-11	R
XXXXXXX	2001011	2001-02-01	R
XXXXXXX	2001011	2001-03-08	R
XXXXXXX	2001013	2001-02-01	R
XXXXXXX	2001014	2001-03-02	P
XXXXXXX	2001022	2001-03-26	R
XXXXXXX	2001023	2001-03-01	R
XXXXXXX	2001023	2001-03-01	R
XXXXXXX	2001024	2001-08-01	R
XXXXXXX	2001031	2001-05-04	R
XXXXXXX	2001033	2001-04-01	P
XXXXXXX	2001041	2001-05-17	R
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XXXXXXX	2001063	2001-07-01	R
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XXXXXXX	2001064	2001-07-05	R
XXXXXXX	2001064	2001-09-01	R
XXXXXXX	2001073	2001-07-18	R
XXXXXXX	2001082	2001-09-10	P
XXXXXXX	2001102	2001-11-10	R
XXXXXXX	2001102	2001-11-01	R
XXXXXXX	2002012	2002-02-04	R
XXXXXXX	2002022	2002-03-01	R
XXXXXXX	2002022	2002-03-01	R
XXXXXXX	2002022	2002-03-01	R
XXXXXXX	2002022	2002-03-01	R
XXXXXXX	2002022	2002-03-01	R

Information concerning the R&M sample

Chassis numbers

XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX

XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX
XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX	XXXXXXX

Appendix 2

Scania fortsätter uppföljningen av kostnadspåverkande faktorer

Scania Sverige har under hösten genomfört intervjuer med kunder för ett utvalt antal fordon.
I populationen ingår fjärrbilar med Grönt Kort avtal spridda runt om i Sverige.
Denna information är tänkt att användas som en del i Scania Sveriges vidareutveckling av den befintliga reparations- och tillsynsavtals prislistan men också som ett underlag för bättre uppföljning av kostnader på avtal.

Scania CV är nu intresserade av att fortsätta på samma spår men önskar bredda informationen genom att samla in styrenhetsdata från samma fordon. Detta är en uppföljning för att Scania, tillsammans med reparationsstatistik, intervjuer och fordonsdata, ska bli bättre på förväntade reparationer, prestandadiskussioner etc.

Följande fordon på ert distrikt är berörda för utläsning av driftdata

Chassinummer
XXXXXXXXXX
XXXXXXXXXX

Vi önskar att ni *så fort det är möjligt* laddar ner driftdata fil från Diagnosprogrammet SDP2.
Lämpligt tillfälle kan vara nästkommande tillsyn, eller nästa planerade reparationstillfälle.

Tack för Er medverkan!