Abstract

This project is a pre-study for a new Central gear assembly line concept for the central gear assembly at Scania axles in Falun, Sweden. The project is based on the theories of lean production, design for assembly and extensive competitive benchmarking. This interdisciplinary study is the first of its kind for the Scania central gears since it consider aspects of product development and production systems.

The purpose of this project is to propose an assembly line concept for Scania's central gears and recommend method and product alterations that will allow a rational assembly process in accordance with the principles of Scania's Production System.

An important delimitation in the project was that the existing assembly lines were not to be taken into consideration. This was to ensure that our minds were open to new possibilities regarding assembly methods and flows. An extensive benchmarking study was done, comparing Scania's products and assembly lines to the largest competitors on the commercial vehicle market, Volvo, MAN and Mercedes. Other comparisons were also made, e.g. by disassembling a Toyota Land Cruiser central gear. Furthermore, a DFA (Design For Assembly)- analysis was performed in order to identify weaknesses in the design of the Scania products from an assembly point of view.

After deciding on the most promising methods and product alteration an investment estimate calculation was made for each proposal and a time plan was developed made as a proposal of when the different proposals should be implemented. The assembly line proposals have been balanced for four different capacity levels to estimate the resources that they require. We also provide a number of areas where Scania can continue the work initiated by us.

In conclusion we discovered that there are many potential improvements and rationalisations to be made both in the assembly system and the product design. The throughput time and the number of operators can be reduced significantly, without large investments, by revising the assembly flow and line layout. However an improved assembly line layout requires improvements in the following areas: Pinion preload adjustment, measuring and product transportation system. Improving these areas will reduce waste of rework, processing and transportation.

Resumen

Este proyecto es un estudio previo para una nueva línea de ensamblaje del grupo diferencial, para la línea de ensamblaje de Scania axles en Falun, Suecia. El proyecto se basa en las teorías de *lean production*, diseño para el ensamblaje y una comparación de la compentencia.

El propósito de este proyecto es proponer una posible línea de ensamblaje para las líneas de grupos diferenciales de Scania, y recomendar modificaciones a los métodos de montaje y productos que permitirán un proceso de ensamblado racional en acuerdo con los principios de los Sistemas de Producción de Scania.

Una delimitación importante en el proyecto era que las líneas de ensamblado existentes no debían ser tomadas en consideración. Esto debía asegurar que nuestras mentes se encontraban abiertas a nuevas posibilidades sobre los métodos de ensamblaje y de flujos. Un estudio fue realizado, comparando los productos de Scania con las de sus más grandes competidores en el mercado de vehículos comerciales, Volvo, MAN y Mercedes, las líneas de montaje de estos competidores también se incluyó en el estudio. Otras comparaciones fueron también realizadas, como por ejemplo, al desmontar un grupo diferencial de un Toyota Land Cruiser. Además, un análisis DFA (diseño para el ensamblado por sus siglas en inglés) fue realizado con el fin de identificar las debilidades en el diseño de los productos Scania desde el punto de vista del ensamblaje.

Luego de decidir cuales eran las modificaciones a los productos y métodos más prometedoras, un calculo de estimado de la inversión fue realizado para cada propuesta y un planning fue desarrollado para indicar el momento en que cada propuesta debería ser implementado. Las propuestas de las líneas de producción han sido equilibradas para cuatro diferentes niveles de capacidad para estimar los recursos necesarios. También proveemos un cierto número de áreas en las que Scania podría continuar con nuestro trabajo.

En conclusión, descubrimos que existen numerosas mejoras y racionalizaciones que pueden ser hechas tanto en las líneas de ensamblaje como en el diseño del producto. El tiempo de montaje y el número de operadores pueden ser reducidos significativamente, sin grandes inversiones. Sin embargo, un trazado de la línea de ensamblado mejorado requiere reformas en varias áreas, estas mejoras reducirá el gasto de trabajo, procesamiento y transporte.

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1 Introduction

1.1 Problem formulation and purpose

This Master Thesis is meant to serve as a pre study for a modern assembly concept for all central gear models at Scania axles in Falun, Sweden. It shall also provide valuable information to the development process of future central gear families.

The purpose of this Master Thesis is to propose an assembly line for Scania's central gears and recommend method and product alterations that will allow a rational assembly process in accordance with the principles of Scania's Production System.

The aim is to propose one assembly line adapted to the central gears of today, and one assembly line adapted to central gears that have product alterations that we propose. The product alterations are meant to enable a rational production process. The principles of lean production (SPS) should be implemented in the assembly lines. A significant part of the work is to identify differences in other manufacturers' assembly methods and products that enable a more rational production process. The objectives of the thesis are listed below. The objectives have been decided in congruence with tutors and management at Scania axels.

1.2 Project objectives

- Describe methods that enable a rational assembly process.
- Propose short-term and long-term product alterations that would enable a rational production process.
- Identify differences in other manufacturers' products that enable a more rational production process
- Present an assembly concept for all central gear models supported by the principles of the Scania production system.
- Estimate a preliminary investment level for the proposed methods and product alterations.
- Create a staffing matrix for the assembly concepts.
- Estimate a time schedule for the implementation of the project.
- Improve the working environment in comparison with today's assembly line.

2 Background and delimitations

2.1 Background

Fierce and global competition forces companies to produce high quality products at low costs. This phenomenon is evident in the automotive industry, where the Japanese philosophy lean production has become successful and where Toyota, who are credited with creating the philosophies of lean production, are world leading.

To gain competitive ground Scania has adapted the Toyota production system to its business and developed the Scania Production System (SPS). The result is a production system driven by the customer demand, where available resources are used to their maximum and wasteful activities are constantly being eliminated.

Rational assembly requires more than a rational production system. For a cost intensive process like assembly, tremendous savings can be made if the products have a design that enables an efficient assembly process. Methods that have proven useful are Design for Assembly and benchmarking.

2.2 Delimitations

The assembly line that exists today and its methods should not be taken into consideration. No workshop- floor or facilities limitations are addressed in this report. The material supply to the proposed assembly lines is not taken into consideration, it is assumed that the material is in place when needed. The methods and product alterations suggested will not be described in detail. Only their basic functions and characteristics will be explained. Screw driving methods have been excluded because of the vast number of standardised screw driving equipment that exist in the market today. The theoretical frame work will be focused on the design and construction of assembly lines.

These delimitations and priorities have been made because of the report’s size and time limits and the many different aspects of technology and management areas that the project comprises.

3 Scania CV AB

3.1 History

Scania CV AB war founded in 1891under the name Vabis. At first, they made railway wagons, but in 1902 they started to build trucks and cars. In 1911 a falling market led to a fusion between Vabis and one of its competitors Scania forming the company Scania-Vabis. In 1969, another fusion, with Saab, changed the name to Saab-Scania. In 1992 Scania and Saab were separated again and Scania CV AB took the form it has today.

3.2 Scania today

Today Scania CV AB is the world's fourth largest make of commercial vehicles and industrial marine engines (figure 2.1). Scania develop, manufacture and market trucks with a gross vehicle weight of more than 16 tonnes intended for long distance haulage and buses with high passenger capacity for use as tourist coaches, inter- city transportation and urban traffic.

Scania has over 30,000 employees in Europe and Latin America. Scania's main markets are Europe, Latin America and Asia. All product development is conducted in Sweden with production units in Argentina, Brazil, France, The Netherlands, Poland, Russia and Sweden. Altogether Scania is represented in over 100 countries through local service and distribution centers (Annual report 2004).

Figure 2.1 The Scania products

3.3 The modular concept system

The modular system means that all Scania components have standardised interfaces which allows them to be combined with all other related components. The modular system optimizes the total number of main components that are included in Scania's product range. It thereby allows considerably longer production runs for these components than is possible in a conventional product system. The modular system is the basis for product quality. It also simplifies parts management and contributes to higher quality in the service organization (Scania Strategic platform 2006).

Figure 2.2 Scania Falun production site

figure 2.3 Scania Falun products

3.4 Scania axles in Falun

Scania axles in Falun started its production in 1975 and produce front axles, rear axles, support axles and propeller shafts (figure 2.3) for Scania vehicles sold on the European market. The production site in Falun is situated in the middle of Sweden, some 250 km north west of Stockholm and has about 700 employees. In figure 2.2 a picture of the Scania Falun site can be seen. The central gear assembly is part of the rear axle production.

4 Theoretical framework

4.1 Lean Production

The term lean production was coined in 1990 by the authors of “The machine that changed the world” (1990) Womack, Jones and Roos. It originates from the now famous Toyota Production System and Just-In-Time philosophy which were developed by Eichi Toyoda and Taiichi Ohno of the Toyota motor company (Womack et al. 1990). After World War Two Japan and its organizations suffered from the effects of war, resources were strained, the workforce exhausted and the old manufacturing plants destroyed or outdated (Askin & Goldberg 2002). With smaller production volumes per part and limited resources there was a need for developing a manufacturing system that was flexible and consumed less resources. The basic principles was to produce only that demanded by the customers at the time when they demanded it and eliminating all types of production waste (Metall 2002).

In the beginning of the 1980’s the western automotive industry realized that Toyota and Japanese car manufacturers in general achieved higher productivity and better quality than their European and North American competitors. The sensational thing was that they achieved this using fewer resources than western manufacturers, their production was “leaner” (Womack et al. 1990).

4.2 SPS – Scania Production System

The Scania Production System (SPS) is basically an adaptation of the Toyota Production System (TPS) to Scania’s business. In continuation all parts of SPS and the theories on which it is based will be explained.

4.2.1 Value

Lean production is a value based system and one must understand the term value in order to implement lean production in practice. Value is everything that the final customer is willing to pay for, hence it is the final customer that defines the term value. It is easiest expressed in terms of a specific product meeting the customers need at a specific time. This is why the product exists from a customer’s point of view (Womack & Jones 2003). Activities that do not add value to the final product are considered waste. By eliminating waste it becomes easier to focus on the value adding activities and the organisation will be more cost efficient (Quest 1999). The theories and principles of lean production will be explained using the Scania production system.

4.2.2 The Scania House

The Scania Production System is visualized as a house (figure 3.1). The foundation of the house is built on three philosophies (Ekman 2001):

• Customer first
• Respect for the individual
• Elimination of waste

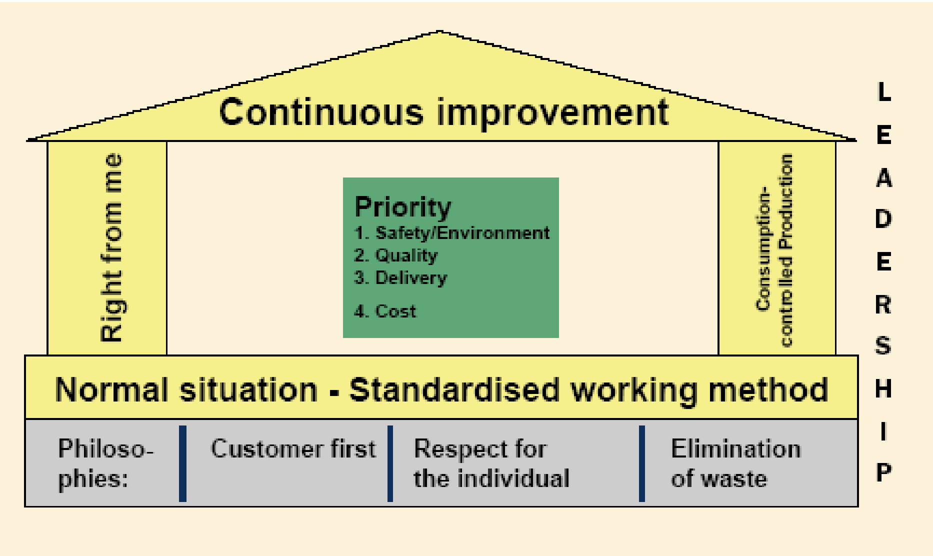


Figure 3.1 The Scania house

4.2.3 Customer first

Scania focuses all its efforts on the needs and business operations of its customers. The customer is at the centre of the entire value chain. Through knowledge of the customer's needs, and by viewing its business over a vehicle's entire life cycle, Scania creates a partnership with the customer (Annual report 2004).

4.2.4 Respect for the individual

The maximum amount of responsibility and tasks should be transferred down to the workers who are actually adding value to the final product and the knowledge of each worker should be used to a maximum (Womack et al. 1990). No one should be discriminated because of their thoughts, political opinion, race, religion, gender, age or background (Annual report 2004).

4.2.5 Elimination of waste

The elimination of all types of waste is the fundamental objective of lean production. There are seven types of waste (Baudin 2002).

1. Over production. There is no reason to produce anything that cannot be sold or that is not necessary at the moment. To produce more than the demand generates material and energy waste. Machines will wear out faster, over capacity is hidden, more products need to be handled and buffers of WIP (work in progress) will be created. Over production is the most serious type of waste since it creates the other six types of waste (Askin & Goldberg 2002).

2. Waiting. Shortages of parts or subassemblies are the most common type of waste (Baudin 2002). Waiting for information which is not available, pending repairs of machinery and poorly balanced assembly lines are other sources of waiting waste (Quest 1999).

3. Transportation. Unnecessary transports of material or WIP between work stations or facilities (Quest 1999). To arrange work stations by, for example, placing the end of one station at the beginning of the next eliminates the transportation waste between them (Askin & Goldberg 2002).

4. Process. This is very difficult to detect since it requires detailed knowledge of the process (Baudin 2002). Unnecessary controls, double work, bottlenecks, not working according to the operating standards or unnecessary information handling are examples of process waste (Quest 1999).

5. Excess inventory. Inventories or buffers of raw material or WIP which are larger than necessary for production can be very costly (Quest 1999). They also hide problems and prevent them from being solved (Ekman 2001)

6. Motion. In assembly, all motion which is not putting a detail onto the product to be assembled is waste. This includes: bending, reaching, stretching, lifting, turning, walking (Quest 1999).

7. Defective products. Defective products incur cost, consume resources and negatively impact customer perception (Askin & Goldberg 2002). In production they cause rework, delays and scrapping of products (Quest 1999).

4.2.6 The four priorities

Whenever there is a deviation from the normal situation the four priorities inside the Scania house are used to make a decision. When making an investment or performing a study the results should be evaluated in the priority order (Ekman 2001).

Safety/Environment

The safety of the individual is always the first priority of Scania, this goes for personnel, customer, supplier and those affected by Scania and its products. The environment in which we live is the foundation for our continuous existence and well being, to protect it from pollution, noise etc is essential and should never be compromised (Ekman 2001).

Quality

Scania is never to deliver products below its high set quality standards (Ekman 2001).

Delivery

Everything is to be done so that the customer receives its product on time and with the quality and security expected from a Scania product (Ekman 2001).

Cost

Eliminate all waste and activities that do not generate value (Ekman 2001).

4.3 The basic principles

In SPS there are four basic principles that form the pillars and roof of the SPS-house:

- Normal situation – standardised working method
- Right from me
- Demand driven output
- Continuous improvement

4.3.1 Normal situation – standardised working method

There can be no improvement if there are no standards (Imai 1986). The standards should be the best known way to perform an operation with the current machinery, knowledge and personnel. The operations should be performed in exactly the same manner and order by everyone (Quest 1999). The normal situation comprises a takt time, a levelled and balanced flow throughout the entire production chain and a visual work flow (Hallberg 2002).

4.3.1.1 Takt

Takt time is the time elapsed between two successive unit completions or the interval at which products leave the assembly line. It is defined as the available production time divided by the demand (Baudin 2002). The takt reflects the pace of sales in the market. The takt-time is constant until the demand is changed on a long- term basis (Ekman 2001). The easiest way to adjust to a new demand is to change the number of products or conveyor fixtures in the assembly line without changing its speed and then adjust the size of the work force and the number of operations to be performed at each position (Vestman). Small short-term variations in the demand are solved primarily by flexible working hours and planned stoppages (Hallberg 2002).

4.3.1.2 Levelled flow

Producing some products requires more effort than producing others. To maintain the level of efficiency and ensure that equipment is used efficiently, physically-demanding jobs should be phased at an even level throughout the production time. Material flows, too, should be levelled (Ekman 2001). The whole product mix is to be produced in the same flow. Difficult variants are assembled using andon operators or separate assembly flows (Hallberg 2002). An Andon operator is a worker assigned to an assembly line without a specific task. This worker is an extra resourse to be used where extra resourses are needed in order to keep the line moving.

4.3.1.3 One piece flow

A one piece flow means that the product being worked on is moving constantly down the assembly line without intermediate stops in buffers and waiting lines. A one piece flow minimises WIP and has many advantages over bench assembly (Baudin 2002):

- It is easier to assure that one product leaves the assembly line each takt time
- A new worker can gradually learn the assembly work taking it one position at a time
- In bench assembly the entire product needs to be learned at once.
- There is only one delivery position for the raw material and the finished product.
- Only one set of tools equipment and gauges are needed.

4.3.1.4 Balanced flow

Activities should be divided evenly within and between work stations throughout the assembly flow (Ekman 2001). Using flexible movable equipment makes balancing and rebalancing easier as it's often required to move or replace it (Hallberg 2002).

4.3.1.5 Visual work flow

It should be easy for everyone to see what is normal and abnormal, this can be done using process follow-up on information boards and visual buffers (Ekman 2001). It must be easy for a worker to alert his co- workers if a problem has, or is about to, occur. Andon lights (Figure 3.2) or sounds and verbal communication between the workers are important tools to accomplish this (Hallberg 2002). Designing U- shaped assembly lines one reduces the distance that operators have to travel in order to help a fellow worker. The U- shape increases the line's flexibility since one worker can perform operations at both the beginning and end of the line within a takt. However, the benefits of a U-shaped cell are dependent on the size of the product, as material supply can be complicated for large and heavy products (Baudin 2002).

Figure 3.2 Andon light

4.3.1.6 Real time

Real time means that there are no delays in the production system. This implies, among other things, direct feedback to the person who caused a fault so that it is attended to immediately. Things are seen straight away and acted upon immediately (Ekman 2001). Information must be presented when it is fresh and to the people it concern. Some information does not concern everyone, only information that facilitates work should be visualized. Andon systems can be used to identify disturbances and to minimise their consequences (Hallberg 2002).

4.3.2 Right from me

Right from me, means to do things properly, right from the start. In short to have the right tools, the right instructions and to use methods that make it impossible to do things wrong (Ekman 2001). There are many different ways to come about this. Dr. Shiego Shingo describes four approaches in his book “Zero Quality Control”, which all can be combined to fit a specific process. These are:

4.3.2.1 Source inspection

Source inspection keeps errors from becoming mistakes. To put it in another way, “*something controls the doing so that it cannot be done wrong”* (Productivity press 1997). For example, a part cannot be processed if fed upside down, a pin physically prevents insertion of a work piece the wrong way (Shingo 1986).

4.3.2.2 100 percent inspection

By inspecting every single product no defects can slip by. Today many companies use statistical quality control which means that a certain percentage of finished products are checked for defects. This gives the company an idea of whether the assembly process is under control but it does not prevent defects nor guarantee that only a statistical number of defects will occur (Shingo 1986).

4.3.2.3 Immediate feedback

By informing an operator or a machine of a defect as soon as possible one reduce the number of possible similar defects to be produced. This is very important when the production rate is high since a machine that is not working properly can render a large number of products useless (Shingo 1986).

4.3.2.4 Poka- Yoke systems

A Poka- Yoke system is a sensor or other devise installed in processing equipment to detect errors that might slip by the operator (Poka- Yoke is also known as Jidoka in the literature). When the Poka- Yoke system detects an error it automatically shuts down the equipment or gives a warning signal. Poka- Yoke systems can be designed in many different ways (Shingo 1986). A few examples are screw drivers that check the tightening torque, holders that ensure that a tool has been used, photo optic devices to control that a part has been picked, counters checking that an operation has been performed a certain number of times, cameras that make sure that parts are fitted the right way and so forth.

4.3.3 Consumption controlled production – Pull system

Consumption controlled production means that production is not started until the customer, or the next process, has signalled a need. This is called a Pull system because the customer pulls the product through the production. The opposite is a Push system where products are produced at full capacity and are then stored until sold. To create a simple and secure link between two processes, the flow of information must always mirror the actual physical flow. This gives a self-regulating system that works in real time (Ekman 2001).

4.3.3.1 Kanban

The word kanban comes from the Japanese word for card. It is a production control system that can be implemented without advanced information technology. Via a kanban, a successor work station communicates with a predecessor work station, requesting parts as soon as it has completed its work. The kanban can have information on what part is required, number of parts required, where the parts should be transported, etc. Kanbans exists in many forms, e.g. as a card or an electric signal in an IT-system. Using kanbans results in a coordination of the production level between the work stations. A kanban system is essential in a lean production system (Askin & Goldberg 2002). The principle of the physical and information flow is shown in figure 3.3

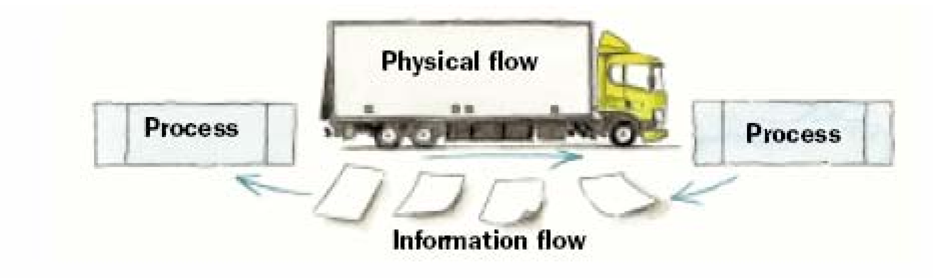


Figure 3.3 The Kanban principle

4.3.4 Continuous improvement - Kaizen

Kaizen means continuous, incremental improvement and is one of the basic principles in lean production. The lean manufacturer is never satisfied and is always striving for improvement. If no improvements occur, there is a risk of competitors eventually taking over. The challenge is to find areas to improve. To find these areas, it is vital to visualize all deviations and force them to the surface. This can be done by reducing the producing unit's resources and eliminating waste (Imai 1986). In an assembly line it's important to do the improvements in small steps. Small steps mean small risks and quick implementation. It is important to make sure that an assembly line is prepared for an eventual increase in demand or for future product families.

The technology level in the assembly line should be as low as possible without lowering the standards for desired functionality. Simple solutions are easier to analyse and improve than complex solutions, complex solutions are also often expensive to improve. (Hallberg 2002)

4.4 DFA

4.4.1 What is Design for Assembly?

Design for Assembly (DFA) is a subset of Design for Manufacturing (DFM), and aims to minimize the cost of assembly (Ulrich & Eppinger 2003). In order to achieve an efficient production, it is important that the product is adapted to the production process. DFA is a work procedure for achieving this, making the product suitable for rational assembly. DFA is not a specific method, it is the name of several work procedures with aim of simplifying the product with assembly in focus (Eskilander 2000).

4.4.2 Benefits from DFA

DFA has proved to be a successful way of cutting costs (Eskilander 2000). The potential effects of DFA are illustrated in Figure 3.4. The advantages of DFA can be classified in two categories:

Short term benefits

By reducing the number of components, all costs associated with the part (assembly, documentation, handling, storing etc.) will be eliminated or reduced. Fewer parts mean shorter assembly time, lower manufacturing costs, lower assembly cost and higher quality (Eskilander 2001).

Long term benefits

DFA is an enabler of concurrent engineering as it forces assembly to be considered in an early stage of the product development process. Product quality will improve as the complexity of the assembly process and assembly difficulties are reduced (Eskilander 2001).

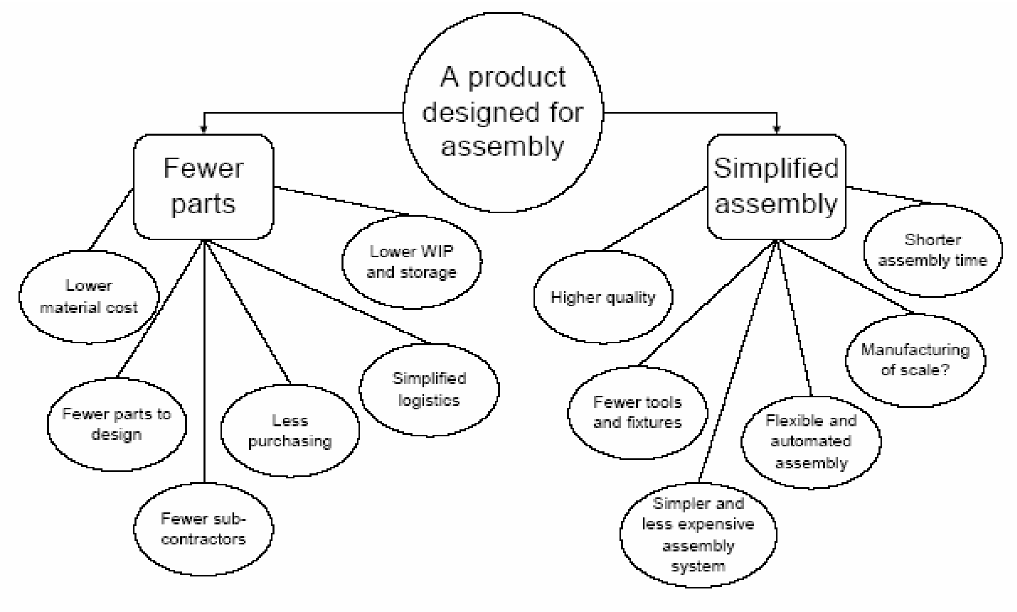


Figure 3.4. Potential effects from DFA (Eskilander 2001)

4.4.3 DFAA (Design for Automated Assembly)

DFAA is a method developed by S. Eskilander and it aims to design products suitable for being assembled by machines and robots. However it has been shown that a product designed for automatic assembly is easier for a human to assemble as well (Maczka 1985). Furthermore, designing for automatic assembly means that automating the assembly line in the future is less troublesome since the product is designed for it. Here are some design factors that should be taken into consideration.

4.4.3.1 Number of parts

The larger the number of parts is, the more complex the assembly process becomes.

4.4.3.2 Standard components

For standard components there are corresponding standard tools. Standard components and tools are less expensive, easier to replace and easier to maintain than custom made components or equipment (Ulrich & Eppinger 2003).

4.4.3.3 Assembly directions

The number of assembly directions greatly affects the complexity of assembling a product. The ideal is for all components to be assembled from above. This way the assembly is never inverted, gravity helps to stabilize the partial assembly and the operator can generally see the assembly location. Three or more assembly directions should be avoided if possible since each change in direction adds material handling waste (Ulrich & Eppinger 2003).

4.4.3.4 Base object

A base object is a part of a product which is used as a fixture for the rest of the details that are to be assembled. A base object eliminates the use of additional assembly fixtures which means that transportation of the product down an assembly line becomes less complicated (Eskilander 2001).

4.4.3.5 Integration and elimination of parts

Integrated parts do not need to be assembled (this could be said to be done when manufactured). Integrated parts are often less expensive to fabricate then the separate parts put together. Integrated parts allow the relationships of critical geometric features to be controlled by a part fabrication process rather that an assembly process. This usually results in more precise dimensions (Ulrich & Eppinger 2003). A method to evaluate if a part is a candidate for integration or elimination is to answer three questions (Eskilander 2001)

1. Is the part in movement in relation to other, already assembled parts during normal usage of the completed product?
2. Does the part have to be from a different material than previously assembled parts or isolated from them?
3. Does the detail need to be separated from other parts because assembly or disassembly otherwise is made impossible?

If any of these questions can be answered with “yes” the parts have reason to be separate. Otherwise the part can in theory be integrated or eliminated.

4.4.3.6 Shape

Parts should preferably be symmetrical which allows them to be assembled in more than one way. If this cannot be achieved, parts should be clearly asymmetrical so that the part can be easily orientated for assembly. A part’s symmetry can be tested by evaluating α-symmetry and β-symmetry. The α-symmetry refers to “*how many degrees the part has to be rotated around one of its ends to regain the same geometrical properties it had in the first position. The β-symmetry refers to how many degrees the part has to be rotated around its axis of insertion to regain the same geometrical properties it had in its first position*.” (Eskilander 2001). Figure 3.5 shows α-symmetry and β-symmetry for different objects.

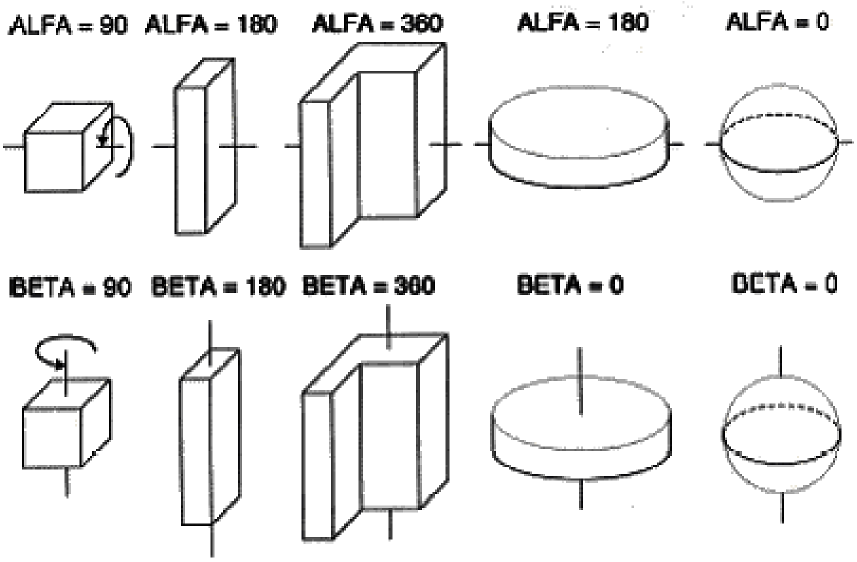


Figure 3.5 α - and β- symmetries

4.4.3.7 Accessibility

Accessibility during the assembly operation should be easy. Obstacles for using equipment such as screwdrivers should be avoided.

4.4.3.8 Fastening

Ideally tools are not required to fasten parts. The number of fastening elements usually determines assembly time. One can minimize the number of fasteners by integrating fasteners in parts (e.g. snap-fits). Moreover should different types of fasteners be minimized, e.g. by standardizing screws, so that the product contains less screws of different shapes and dimensions. (Eskilander 2001)

4.5 Benchmarking

Unless a company enjoys a complete monopoly, benchmarking is a crucial part of developing new products, methods or services. Benchmarking competitors or other related businesses is by far the most efficient way of determining the existing technology and solutions incorporated in the products on the current market (Ulrich Eppinger 2003). By benchmarking different competitors' one can "pick the raisins out of the cake", combining the best solutions in one product. The information can also be used as a reference point for the development of new solutions.

There are four types of benchmarking; internal, competitive, functional/ generic and strategic (Fernandez et al. 2001). The first three are described below, the fourth has been left out since it is not relevant in this project:

4.5.1 Internal benchmarking

Internal benchmarking is primarily conducted within a company's departments and business units. The advantages of internal benchmarking are the easy access to all information and transferability of processes is often simple. The drawbacks are that the processes may not be the best in class (Fernandez et al. 2001). Best in class refers to the most rational way to perform a task or process. This is also called best practice.

4.5.2 Competitive benchmarking

Competitive benchmarking, if successful, can lead to a great number of improvements in the own organisation. It can save years of research and development and it can stimulate creativity internally. The difficulty is accessing the information of the competitor (Fernandez et al. 2001).

4.5.3 Functional benchmarking

Functional or generic benchmarking is performed in organisations that are not in direct competition with the own company but has some related functions (Fernandez et al. 2001). For Scania it could be the car, aviation, or naval industry since these produce vehicles with some comparable functions and products that are not in direct competition with the commercial vehicle industry. It can also be companies with a lean production system or another comparable characteristic. Functional benchmarking can create partnerships and rewards with other organisations. Accessing information is often simple but processes are usually not directly transferable to the own processes (Fernandez et al. 2001).

4.6 Assembly line human factors

4.6.1 The costs of accidents

Health and safety issues have traditionally been considered as an expense or a cost in production by many industrial managers. For companies overlooking these potential problems the final cost can be far greater than that of pre-emptive measures.

One of the most wasteful activities in the industry today is an accident. If an employee is injured there are the obvious costs of medical treatment, salary during the workers recovery time, a replacement worker and so forth. However when an accident occurs there are many hidden costs that can be greater that the obvious ones. These are: Potential lawsuits, machine downtime, production stops, damage to equipment or product, investigation time, potential overtime, a negative effect on the injured worker and his working colleagues, negative publicity and measures to prevent the accident from repeating itself. Integrating sound health and safety techniques can control and minimize this waste (Savasta 2003). This is a prioritised area in all of Scania as the first priority in SPS is safety and environment (Ekman 2001).

4.6.2 Workstation ergonomics

The basic principle of ergonomics is to fit machines and tools to humans and not the other way around (Smellie 2003). The design of a workstation can have a great impact on productivity and manufacturing costs. A working surface which is slightly too low, a part which is positioned slightly beyond the employees’ reach or inadequate lighting have a negative influence on an operators efficiency, safety and motivation. The amount of productivity lost from a badly designed workstation can be greater than that caused by actual illness (Bosch 2004). There are some fundamental aspects to consider when designing a workstation. In continuation we will describe those which can be improved while designing an assembly line.

4.6.2.1 Variation

The workstation should be designed and equipped so that the operator can assume comfortable working positions and be able to variated positions and movements. Sitting or standing still for a long period of time can be dangerous. Equipment or inventories which by design or placement allow the operator to perform different and varied moves can prevent this (Börjesson 2003)..

4.6.2.2 Moving space

There should be enough space for arms and legs at a work station. The largest male (i.e. a male larger than 95% of the population) should be used as a reference (Börjesson 2003),

4.6.2.3 Reach

There are basically two areas of reach: The first, the dark green area in figure 3.6, where both hands work within the field of vision and the second, light green area in figure 3.6, where the vision has to be moved (Börjesson 2003). Preferably all work should be performed in the inner dark green area. Tools and components should be place in the light green area.

Components, tools or operations should only be place outside of these areas if lack of space or other logistical limitations prevents it (Bosch 2004). The smallest woman (smaller than 95 % of the population) should be used as a reference (Börjesson 2003).

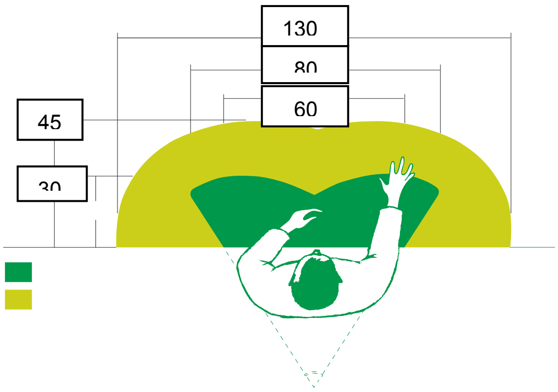


Figure 3.6 Areas of reach

4.6.2.4 Standing working positions

A worker standing up is often more productive than a worker sitting down. Standing up also increases the blood circulation and strains on neck and back (Dainoff 2002). When standing up all operations should be performed keeping the hands above the waist and below the heart, the green areas in figure 3.7 shows the recommended working areas for 95% of the Swedish population (Börjesson 2003). Working within these areas avoid loads on neck and back and assure a constant and sufficient blood flow. This is complicated to achieve with static workstations since the area in which all female and male workers can work is very limited (Bosch 2004).

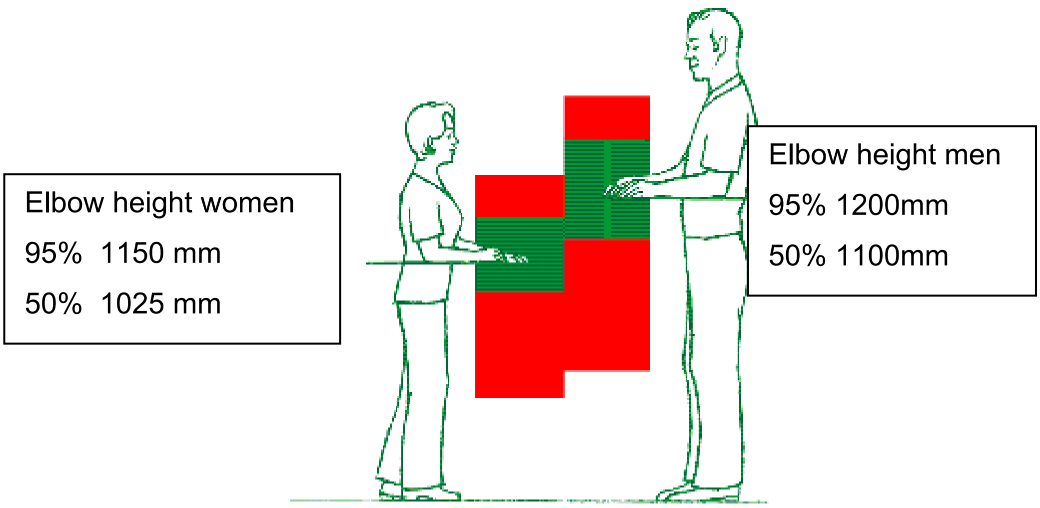


Figure 3.7 Working height

4.6.2.5 Manual lifting and moving of objects

Heavy lifting can lead to serious injuries and extensive wear on a human body (AFS 1998). These injuries can occur instantly by simply trying to lift a heavy object or gradually from repeated lifting and handling of heavy objects (Börjesson 2003). There are many aspects that decide how stressful a lifting or handling operation is on a human body. Every person has an individual capability, strength and body size. Static lifting is a lot more stressful for the body than a dynamic movement since blood supply to the muscles is facilitated during a dynamic movement (Bosch 2004). The objects distance from the body plays a major role due to the lever effect. If the lifting operation requires movement of the body or twisting the torso the stress increase and affects more parts of the body (Börjesson 2003). Table 3.1 show recommended values for weights, frequencies and distances from the body (Lindquist and Wester 2001).

Lift frequency (times/h)	1-10	10-	30-	60-	120-210
Recommended Max weight (kg)	12	7	3	2	1

1. Lifts over 12 kg shall not exist
2. Objects weighing over 5 kg shall be lifted with both hands
3. Objects weighing up to 0, 5 kg can be lifted with an over hand grip
4. Objects weighing up to 5 kg can be lifted with an under hand grip

Table 3.1 Recommended lifting values

4.6.2.6 Surface

The surface on which the worker is standing should be damped and, in combination with proper shoes, easy on joints and the spinal cord (Börjesson 2003).

4.6.2.7 Field of vision

Avoiding unnecessary head and eye movement saves the employee having to repeatedly refocus his/her vision, an action that puts strain on the eyes and increase the risk of errors (Bosch 2004). The natural and most restful vision line when standing is about 15 degrees below the horizontal line (Börjesson 2003). The optimal field of vision is 15 degrees in all directions: up, down and sideways. Materials and tools should be placed within a 180 degree angle in front of the operator to the sides and within a 125 degree vertical angle (Bosch 2004). Proper lighting is essential to perform a task correctly. For general operations a light intensity of 500 Lux is necessary. For precision and detailed work with small components or tolerances an intensity of 1000- 1500 Lux is preferable (Bosch 2004).

4.6.3 Psychological effects of working at an assembly line

Since its invention human factors have been the Achilles heel of the assembly line. Workers generally prefer bench assembly although the assembly line has proven itself to outperform bench assembly in almost every category. Workers tend to feel alienated and bored at the assembly line. The feeling of pride and accomplishment of having assembled an entire product is also lost at the assembly line (Baudin 2002). There is almost always a resistance among workers when lean is implemented. At the first Toyota plant in North America the assembly personnel called it “mean production” or management by stress (Metall 2002). Working under a constant takt means that there is no room for a two minute brake every now and then which can make people feel like human machines. This was a problem for Henry Ford seventy years ago and it is still present today (Womack et al 1990).

4.7 Investment estimations

4.7.1 Net Present Value

This is a simple investment calculation formula (eq 3.1) which calculates the net present value (NPV) of an investment over a given time period in years (n). The basic investment (I) is subtracted from the sum of the annual saving or income (a). The annual saving or income for each year is adjusted using a discount rate or cost of capital (k). If the net present value is positive the investment is profitable within the given time horizon (Martinez 2001). The discount rate currently used by Scania is 11% (Helmersson 2005).

$$NPV = \sum_{j=1}^{n} \frac{a_j}{(1+k)^j} - I \qquad \text{(eq 3.1)}$$

4.7.2 Payback time

This is the time required for an investment to pay itself off i.e. when the NPV is zero. The payback time is often expressed in years or quarters of years. Since the payback time very seldom coincide with these exact dates it is customary to take the first period in which the

NPV is positive as the payback time (Persson 1999). Scania has a restriction that all improvements or small investments should have a payback time of two years or less (Lundquist 2005).

5 Technical background

In order to understand the material presented in this thesis it is important for the reader to have basic knowledge of the products. In continuation the different functions of the central gear and aspects affecting its performance will be described.

5.1 The function of the central gear

The central gear is situated in driving rear axles of commercial vehicles and it transmits the propeller shaft torque from the engine to the driving wheels. The central gear consists of a conical gear set show in figure 4.1 and it compromises a crown wheel (1), pinion (2) and axle differential (3).

5.1.1 Axle differential

When cornering, the driving wheels travel different distances and therefore have different rotation speeds. The rotational difference between the wheels is transferred to the axle differential. The axle differential, shown in figure 4.2, consists of four differential pinions (3) fitted on a differential spider (2). The differential pinions are constantly meshed with two opposed differential gears (1) which are connected to the relevant half shafts. The axle differential is integrated into the differential housing.

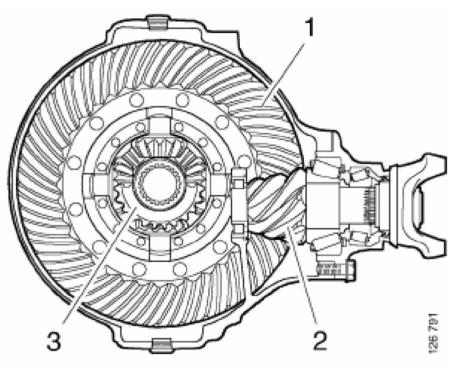


Figure 4.1 Conical gear set

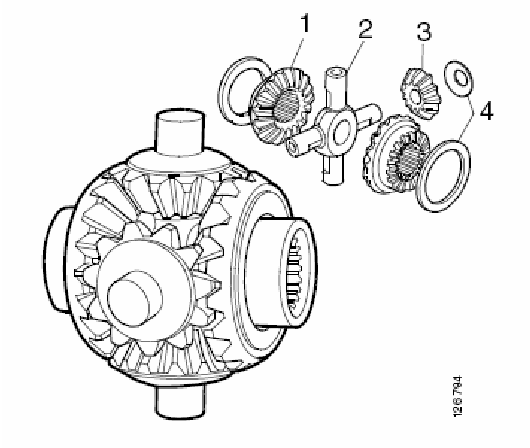


Figure 4.2 Differential and exploded view of differential

5.1.2 Rotational distribution

When the vehicle is driven straight ahead and the rotational speed of the driving wheels is the same, the differential pinions on the differential spider do not rotate but operate only as drivers between the crown wheel and half shafts. See A in figure 4.3. When the vehicle turns, the inner driving wheel will travel a shorter distance than the outer wheel. Since the driving wheels then have different rotational speeds, so do the differential gears on the half shafts. The differential pinions will then rotate. See B in figure 4.3. Since the combined speed of the driving wheels is constant, the outer driving wheel will rotate faster in relation to the crown wheel by as much as the inner one rotates slower. In extreme cases, when one driving wheel is stationary and the other one is slipping, the slipping wheel will rotate twice as fast as the crown wheel. If one driving wheel does not have sufficient friction and starts to slip, the vehicle remains stationary. The friction on the slipping wheels determines the overall amount of torque. This torque determines the driving force for both wheels, since the axle differential always transfers the torque to both wheels.

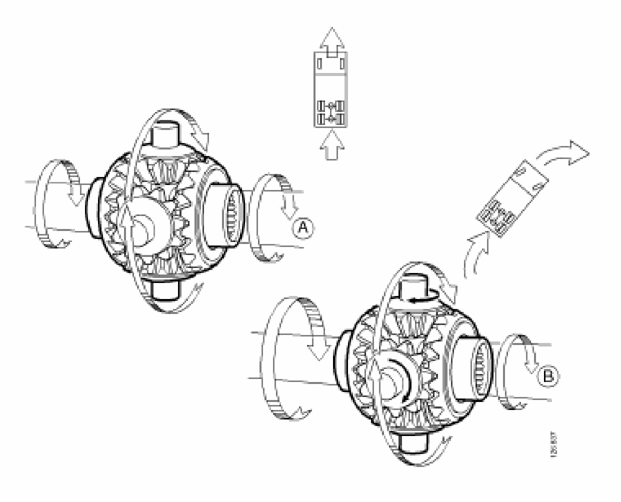


Figure 4.3 rotational distribution in the differential

5.1.3 Axle differential lock

The central gear is equipped with an axle differential lock (figure 4.4) to prevent wheels on the same axle from rotating at different speeds. The axle differential lock has a sliding coupling half on one half shaft. When the coupling half is pushed to the side, it locks the half shaft to the differential housing or the differential housing to the differential gear. The axle differential with the crown wheel and half shaft then becomes a rigid unit and thus forces the driving wheels to rotate at the same speed. The axle differential lock is most commonly used for starting or driving slow on slippery surfaces such as ice or wet mud. Turning with the lock engaged can damage the differential.

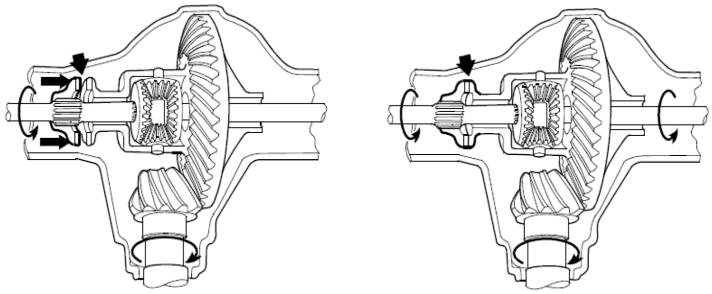


Figure 4.4 Axle differential lock function

5.1.4 Double rear driving axels

On vehicles with double rear driving axles, the front central gear is combined with a bogie differential and one or two transfer gears. In the front central gear, the left axel in figure 4.5, the propeller shaft torque is transferred to the front and rear central gears. Torque transfer takes place in the bogie differential.

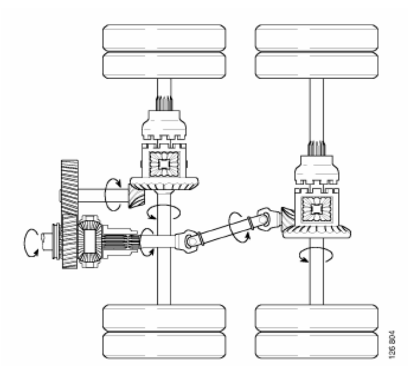


Figure 4.5 Function of the bogie differential

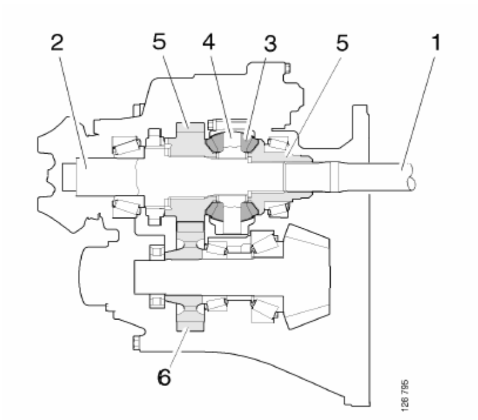


Figure 4.6 Bogie central gear

5.1.5 Bogie differential

When the vehicle turns, the wheels on the two driving axles will travel different paths. The front pairs of wheels travel longer distances than the rear ones. This means that the axles have different rotational speeds. The rotational difference between the front and rear driving axles is distributed in the bogie differential (figure 4.6). It is constructed in the way that a differential spider (4) is connected to the input shaft (2). The differential spider is in constant rotation when the vehicle is moving. The differential pinions (3) on the differential spider are constantly meshed with two differential gears (5) which are connected to the transfer gear (6) and output shaft (1).

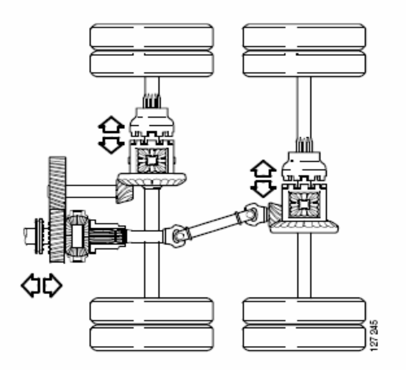


Figure 4.7 The three differential locks

5.1.6 Bogie differential lock

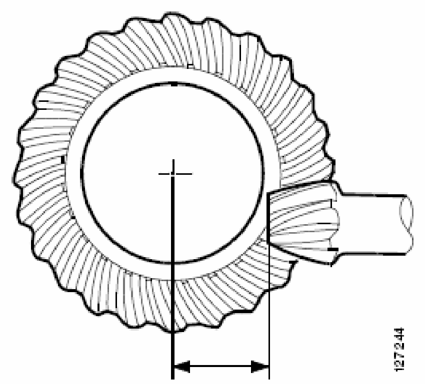
In addition to an axle differential lock on each axle, vehicles with double rear driving axles have a bogie differential lock (figure 4.7). The bogie differential lock prevents the pairs of wheels on the front and rear axles from rotating at different speeds. The bogie differential lock is a sliding coupling half connected to the input shaft.

5.1.7 Differential lock control cylinder

The control cylinder for the differential lock is located on the gear housing. Bogie gears have two differential lock control cylinders, one for each differential lock. The locks are engaged and disengaged using compressed air. The air moves a spring loaded pull rod which actuates a lever. The lever pushes the coupling half so that it meshes with the differential gear or differential housing.

5.2 Mesh image

The teeth of the pinion and crown wheel should mesh in the centre of the tooth under normal working conditions, see Figure 4.9. The mesh location, mesh image, can be checked e.g. by applying paint to the crown wheel's teeth. When running the gear, paint is worn of at the contact points. A badly located mesh image reduces the service life of the central gear and results in a high noise level. The mesh image can be adjusted in the assembly line by either adjusting the distance between the centre of the crown wheel and the pinion (figure 4.8) or the crown wheel's position in the axial dimension (i.e. in or out from the paper in figure 4.8).



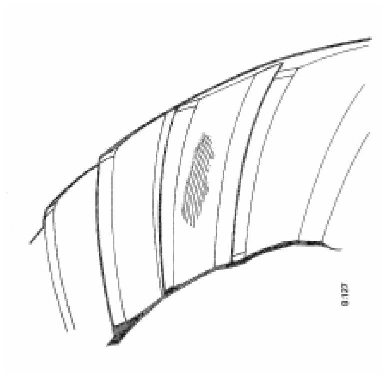


Figure 4.8 Distance between the centre of the crown wheel and the pinion

Figure 4.9 Mesh image on the front of the tooth.

5.3 Backlash

When assembling a central gear it is important to have a small backlash or play between the crown wheel and pinion. This backlash compensates the heat expansion of the two parts under normal working conditions. If the backlash is too great the teeth of the crown wheel and pinion will be struck against each other damaging their surfaces and reducing the gears performance. If the backlash is too small or absent the crown wheel and pinion will be exposed to great internal stresses reducing the time of use for them and other components such as bearings.

5.4 Bearings

Under load the pinion and crown wheel are subjected to forces which seek to push the pinion forward as well as force the pinion and crown wheel apart. Tapered roller bearings are used to counteract the forces. Some central gears have an additional support bearing for the pinion, located in the gear housing inside the crown wheel ring gear.

The crown wheel is assembled with the differential housing which is supported on tapered roller bearings in the gear housing. In Figure 4.10, the support bearing (1), rear pinion bearing (2), front pinion bearing (3) and differential housing bearings (4) are illustrated.

Bearings that are subject to vibrations are preloaded to avoid that the rollers are struck into the bearing races which increases service life of the bearings in the gear (FAG Kugelfischer Georg Schäfer & Co, 1980). Preload is characterised by the absence of axial play, and can be expressed as an axial dimension, rolling resistance or vibration characteristics. However the real measure of preload is in the context of the internal forces captured by the bearings. The bearings are preloaded to increase the service life of the bearings and central gear.

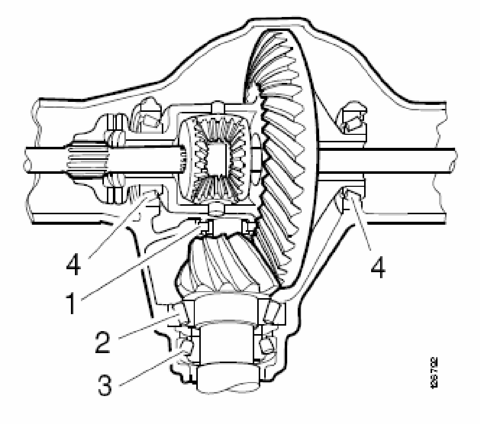


Figure 4.10 Illustration of a central gear with bearings marked.

5.5 The design of the central gear

There are four different types of gears to be considered. These are R, RP, RB, and RBP. The production distribution volumes between the different products is visualized in attachment K. Basically a central gear is made up of a conical gear set described earlier, a differential and a differential lock. These components are situated in a gear housing. At the end of the pinion an end yoke is mounted to connect the gear to the propeller shaft. In attachment D there are exploded views of all the gear types along with English, Spanish and a Swedish index of all components.

5.5.1 R (Reduction)

The R- central gear is a single gear. This is the high volume type of gear and stands for 70% of all central gears produced. There are three models: The R780 which is the largest and is situated in transportation trucks traveling long distances with a medium size cargo load. The R660 and R560 are smaller and lighter than the R780. These are installed in light trucks and buses. The R- gears differ from the rest of the gears since they are designed using a support bearing and a bearing housing.

5.5.2 RP (Reduction, Planetary)

This is a single gear (figure 4.12) placed in axles which have reduction in the wheel hubs instead of the central gear. The wheel hub reduction is indicated by the P in the name. It is almost exclusively combined with a RBP- gear and installed in heavy and demanding applications. Since the reduction is acquired in the wheel hubs the gear ratio between the crown wheel and pinion is close to one and these components are not exposed to the same stresses as the R and RB gears. This results in a different design of crown wheel, pinion, differential housing and coupling half. There are two different versions RP735 and RP835. The latter is the strongest of the two.

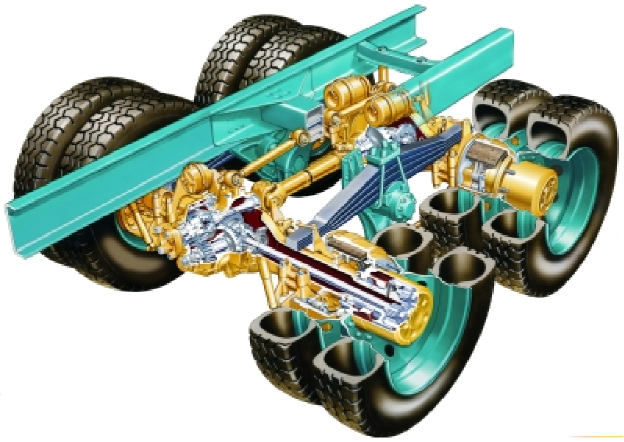


Figure 4.11 RBP835 combined with a RP835

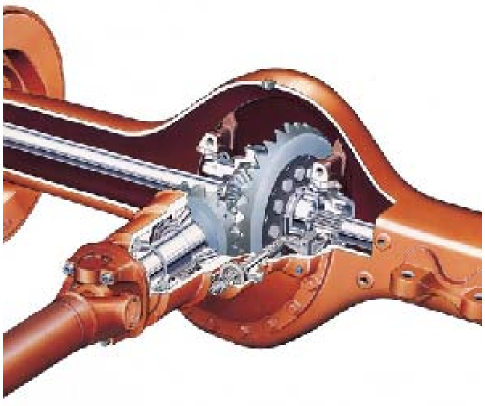


Figure 4.12 RP735 central gear

5.5.3 RBP (Reduction, Bogie, Planetary)

The RBP bogie gear is always combined with a RP single gear. It has most of its reduction in the wheel hubs. As mentioned they are usually installed in demanding application. There are two models RBP735 and RBP835. A RBP 835 gear combined with a RP 835 can be seen in figure 4.11.

5.5.4 RB (Reduction, Bogie)

The RB- central gear is a bogie gear. It is the largest and heaviest central gear included in this thesis. There is only one version of this gear still in production and it is denominated RB662. It is combined with the R660 single gear.

6 Method

6.1 Project overview

When designing an assembly line one usually starts from the existing one in order to improve it and further develop the current assembly methods. This is often done using a VSM (Value Stream Mapping) or another similar method to identify problems, bottlenecks and so forth. Once this is done you try to solve these issues (Rother & Shook 1998).

In this Master's thesis we have used a somewhat different approach. It could be said that we have worked in an inverted order as to what is customary. Our approach was to start from the products and then design an assembly line based on the products characteristics using the guidelines of SPS. At first we studied cross sectional drawings and exploded views of the finished products. From these drawings we started to work on an assembly sequence for the gears. This sequence has of coursed changed many times during our work as we discovered that there were easier and more rational ways to assemble the products. Once an initial assembly sequence had been established we started to look at methods to assemble the gears and product changes that would make the assembly process more rational. As we started to work with our new methods and product alterations we learned more about the central gears and new ideas on how they could be assembled were born. This combined with our new found knowledge of the competitor's products and production generated even more proposals while others were discarded. This iterative process was necessary because of the complexity of the products and the extensiveness of the project. We have tried to keep method and product alterations separate but many product alterations allows other more rational methods to be used and vice versa.

A prerequisite from Scania was that we were not allowed to visit Scania's central gear assembly lines until we had proposed our first assembly line layout. The idea behind not letting us see the current assembly lines was to allow us to keep an open mind and to prevent us from getting stuck in old, outdated ideas of assembly methods and line layout. By the time we got access to the Scania central gear assembly lines we had already visited or benchmarked modern assembly lines at Scania, Arvin Meritor, Daimler Chrysler, Getrag and MAN. We therefore had a different, more open minded approach to the problems involved than those familiar to the current assembly lines.

6.2 Develop theoretical framework

The theoretical framework was established early in the process. This was necessary as we found it important to have a foundation and understanding of the problems in the work ahead. The literature on which this report is based is gathered from a wide range of sources. Most of the literature has been found in the libraries of Scania Falun and Lund University. Several databases have been used to find information, e.g. Scania's database, Elsevier, EBSCO, emerald insight and Esp@cenet. Examples of search words that we used are *lean manufacturing, lean assembly, benchmarking* and *ergonomics.*

6.3 Interviews

There is a lot of valuable and for this project relevant information that never has been written down. This information is instead possessed by people working with related subjects. To access this information it is necessary to perform interviews. There are two types of interview techniques often used for research, structured and unstructured (Svensson & Starrin 1996).

A structured interview means that questions are prepared before the interview. The result can be that interesting subjects may be overlooked. The unstructured interview resembles a discussion, and is freer for both parts. There is however a risk that the interview drifts away from the subject. In this project we have basically been performing unstructured interviews. The interviews have been conducted in several ways, e.g. as discussions after we have presented the progress of our work, visits to and from companies, via e-mail correspondence and telephone calls with representatives from different companies and organisations. People with all kinds of background and areas of expertise (e.g. assembly personnel, manufacturing engineers, salespeople and design engineers) were interviewed, as this project covers many different subjects.

6.4 Benchmarking

A great part of the work for this master thesis has been to perform different types of benchmarking. The benchmarking has generated many assembly methods and product alterations which are analysed in chapter 6.1 and 6.4 respectively.

6.4.1 Internal benchmarking

6.4.1.1 Production sites

We have investigated and analysed the three central gear assembly lines at Scania axles Falun. Furthermore we have analysed other Scania assembly lines built up according to SPS, these are (with their respective names in Swedish) Kombiline, Skiva-bak, Framaxel, nav, motor 9&12, motor 16 and motormåleri. The first four are situated in Falun, Sweden and the last three in Södertälje, Sweden.

The three central gear assembly lines were studied in detail and are described in attachment C. Kombiline, Skiva-bak, Framaxel and Nav were studied during our first introduction week at Scania and basically consisted in assembly work. Our observations during this week are described in attachment A. We have also read a master thesis with similar objectives as this one concerning the Nav assembly line (Englund 2002). The motor 9&12, motor 16 and motormåleri assembly lines were studied during a one day visit at Engine2 at Scania Södertälje.

6.4.1.2 Projects

To consider previous experiences from similar projects we have studied the following Scania projects: Single flow CG SLA, Single flow CG SEU and Single flow RA SEU. The two first refers to the central gear single assembly line projects being conducted in Scania Latin America and Scania Europe respectively. These two projects our very similar to our, as they aim to form a single flow for all central gears. The time studies from these projects have been used in our project and we have had a continuous exchange of information during our project. The latter project has the objective to run all rear axles in the same assembly line at Scania Falun.

6.4.1.3 SLA- project

Single flow CG SLA project mentioned above, from here on called SLA- project, is a pre-study similar to the one that we have done. It is to be implemented in San Bernado, Brazil and it aims to assemble all central gears in on assembly line. In order to compare the two studies and to have an analogy between the them we have used the time studies elaborated by Scania for the SLA- project in this project. The time savings of the different proposals proposed in this project have been estimated using the SLA- time study as a reference.

6.4.2 Competitive benchmarking

Most of the benchmarking conducted has been competitive benchmarking. In Europe the three biggest competitors to Scania are Daimler Chrysler/ Mercedes, MAN and Volvo, see figure 5.1. Since we have studied the central gear we have concentrated on the suppliers of central gears for these three manufacturers. We then end up with three production sites: Daimler Chrysler in Kassel Germany, MAN in Munich Germany and Arvin Meritor in Lindesberg Sweden. These production sites also produce central gears for other manufacturers. The Daimler Chrysler plant produce some central gears for Freightliner, one of the largest commercial vehicle producers in North America and Arvin Meritor produce central gears for Renault and Iveco in their production plants situated in France and Italy respectively.

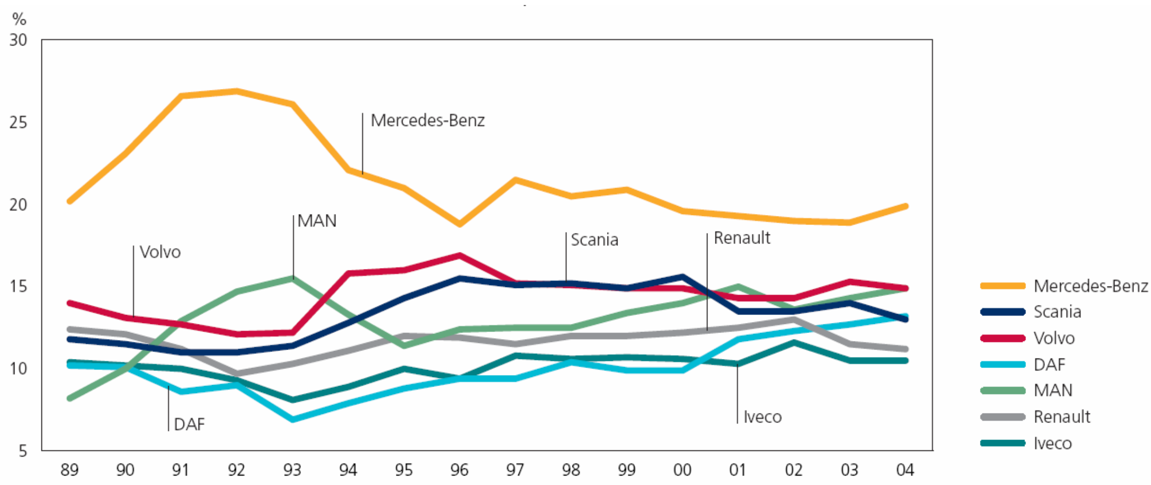


Figure 5.1 market shares, trucks above 16 tonnes in Europe (Annual report 2004)

6.4.2.1 The competitors' production

To benchmark the production sites we had to go about in two different ways, as it was not possible to arrange visits to all of them. We visited Arvin Meritor's plant in Lindesberg where the design engineer *Thomas Nilsson* kindly gave us a detailed and open tour of the plant and answered our questions. The finding of this visit is described in attachment C.1. Benchmarking the Daimler Chrysler and MAN plants was not as straightforward, as there were difficulties in arranging visits for various reasons. The only way for us to benchmark these two production plants was to use the documentation issued by the Scania managers from their visits to the Daimler Chrysler plant in 2004-10-07 and to the MAN plant 2005-09-07. By studying these documents and talking to the people who made the visits we were able to get an idea of how these two manufacturers have chosen to assemble their central gears. The Daimler Chrysler production is described in attachment C.3 and the MAN production in C.2.

6.4.2.2 The competitors' products

At the NAX- department in Södertälje we had access to five central gears. Two Daimler Chrysler gears, two MAN and one Arvin Meritor gear. These are described in attachment E and a summary of this benchmarking can be read in chapter 6.2. We have not compared the bogie gears of the competitors since we have been informed that they are very similar for all manufacturers (Delvén 2005).

6.4.2.3 Patents

We spent many days and hours searching patent databases at Esp@cenet, looking for new solutions and constructions. Patents are a good benchmarking source, as the design and the ideas behind them are described in detail. Moreover the patents give an idea of designs and solutions that either should be avoided or licensed. (Ulrich & Eppinger 2003). We found the patents to be a great source of inspiration. Even though these solutions are protected by law it gives you an idea of what is possible to do. It also is a great source for ideas for future central gears designs.

6.4.3 Generic Benchmarking

6.4.3.1 Production sites

We visited Getrag All Wheel Drive AB in Köping, Sweden. They produce front and rear axles for 4x4 Volvo and Ford cars. We were guided around the production site by the manufacturing engineering manager *Håkan Hamnstedt* who answered our questions. We tried to arrange a visit to a BMW, VW or Haldex production plant as well but it was not possible for various reasons.

6.4.3.2 Related products

At Getrag AWD *H. Hamnstedt* explained the construction of two of their central gears situated in the Volvo S40/V50 and in the Volvo XC90/Ford Freelander cars. These gears are described in attachment F.2.

We disassembled a central gear from a Toyota Land Cruiser. The purpose of this study was to compare the Scania central gears to those situated in a large Toyota car. We chose

Toyota because they are well known for their high quality and rational production. We chose the Land Cruiser because it is a big car of SUV type and its characteristics are more similar to a commercial vehicle than a standard sedan model car. The Toyota Land Cruiser is also produced in large quantities (191,000 sold during 2000) and should therefore be designed for rational assembly. The study was conducted in collaboration with Patrik Karlsson, a revision operator at Scania's central gears assembly CVX. The results of this study can be read in attachment F.1.

6.4.3.3 Patents

We searched for patents to find methods to assemble the gears. We contacted some of the owners of the encountered patents which in many cases led to further discussion and new concepts.

6.5 Method concept scoring

In order to evaluate the different assembly methods that we generated we designed a decision matrix where we gave every method a weighted score based on its relevance and compatibility with SPS. The matrix is based on a product concept scoring matrix described by Ullrich & Eppinger in the book "Product design and development" (2003) and the scores are ranked in the same order of priority as the SPS priorities safety, quality and cost. The third SPS priority, Delivery, has not been included since it is hard to relate to long term changes in our case. The matrix, the method analysis and the results are displayed in chapter 6.1.

6.6 DFAA

The DFAA analysis performed in this thesis is built upon a DFAA-method developed by Stephan Eskilander and published in a Doctoral thesis with the title "design for automatic assembly" (2001). This method is very clear and straight forward and it points out a product's weaknesses without using complex matrixes or graphs. To perform and document our DFAA- analysis we used an excel tool developed for Scania CV AB in a master thesis by Lindquist and Wester with the title "DFA i praktiken". This tool is based on the DFAA-method developed by Eskilander, and can be seen in Appendix H.

To evaluate how well a product is designed for assembly, Eskilander's method provides rules for evaluation. The rules for evaluation have three steps (in some cases just two). The rules are as follows:

- The best solution from an assembly point of view is given 9 points
- An acceptable, however not ideal solution is given 3 points.
- An unacceptable solution from an assembly point of view is given 1 point

According to the method a product with 9 points in every category is a perfect solution. To determine how close a product is to the perfect solution, a percentage is calculated, called “DFA-index”. The DFA-index is obtained by dividing the product’s total score with the optimal score. The DFA-index is essentially helpful for comparing two products. The true strength of the DFAA method emerges as a systematic review of the score in each category is performed (Lindquist, Wester 2001). This is the reason why we have chosen this method, it clearly indicates what the problems and areas of improvement are.

6.7 Other information

6.7.1 Capacity steps

There are four different production volumes included in the analysis in chapter 6. These are denominated Step 0, 1, 2 and 3 respectively. The four steps refer to the production volumes where Step 0 is the current production volumes, Step 1 is the production in the near future and so forth. The exact numbers are displayed in attachment K.

6.7.2 Time savings

The time saved by each new method or product alteration described in chapter 6 are estimations made by us, suppliers and Scania employees. The estimations where made by simply eliminating operations from the SLA- time studies or reducing them.

7 Analysis

In this part of the thesis we will present and discuss our proposals of assembly methods and product alterations. In addition the assembly line layout and balancing will be presented and discussed.

7.1 Assembly methods

In this chapter we present a summary of our analysis of the assembly method proposals. Each chapter begins with a short description of the operation to be performed followed by a description of the demands on the future method. Next, the name of each method proposal is shown along with its respective total score in the SPS analysis. The proposal with the highest total score is then presented and analysed more thoroughly, including the result of the investment estimate calculations and a technical description. For detailed descriptions of discarded method proposals see attachment I.

An example of the method concept scoring matrix is shown in table 6.1. The different priorities in SPS have been broken down into smaller pieces and weighted after their importance (Blue square). Each proposal is then given a score between 1- 5, 5 being the highest, in each of the sections (Yellow square). The score is multiplied by the weight (Green square) and these weighted scores are then summarised in order to obtain a final score for each method (Red square). In the example proposal 1 would be selected since its final score is the highest. To ensure a safe working environment none of the scores in the first group may be lower then 3. Still, hazardous methods are included since they can be made safer with further investigation and development. The matrixes used to judge our different proposals can be seen in attachment J.

		Current method		Proposal 1		Proposal 2	
	Weighting	Score	W.Score	Score	W.Score	Score	W.Score
Accident risk	16,0%	4	0,64	4	0,64	4	0,64
Ergonomics	14,0%	2	0,28	4	0,56	3	0,42
Environment	10,0%	4	0,40	5	0,50	4	0,40
Worker safety	**40,0%**		**1,32**		**1,70**		**1,46**
Standardisation	8,0%	1	0,08	5	0,40	3	0,24
Robustness	8,0%	2	0,16	4	0,32	4	0,32
Cleanliness	8,0%	2	0,16	5	0,40	4	0,32
Right from me	8,0%	1	0,08	5	0,40	4	0,32
Quality	**32,0%**		**0,48**		**1,52**		**1,20**
Process time	8,0%	1	0,08	4	0,32	5	0,40
Flexibility	7,0%	2	0,14	4	0,28	3	0,21
investment cost	7,0%	5	0,35	4	0,28	1	0,07
implementation time	6,0%	5	0,30	3	0,18	2	0,12
Cost	**28,0%**		**0,87**		**1,06**		**0,80**
Total score			**2,67**		**4,28**		**3,46**

Table 6.1 Method concept coring matrix

The investment calculations are based NPV and payback time and are presented in attachment M. The investment levels have been estimated by at least one independent supplier of the equipment. The savings in assembly time are based on a standard annual cost for an assembly worker which is 400000 SEK (Helmersson 2005). The cost for a second of assembly in each capacity step is shown in attachment M. The quality savings are based on the guarantee cost of related parts from January 2002 to December 2005. These costs are shown in attachment L. The quality improvements have been estimated by us in congruence with our mentors at Scania and suppliers of assembly equipment. All method proposals have been investigated and some product alterations as well. Since many of these figures are intended for internal use only the reader may not have access to some of the attachments.

Most of the proposals are the result of a known assembly problem and have been generated through sources such as patents, benchmarking findings and contact with suppliers. A few methods have been generated by other means; one example is the lifting tool which we saw when visiting the Arvin Meritor production plant. Another example is the Pinion Pac which was first treated as a product alteration but the more we investigated it we started to consider it as a method or more correctly, elimination of methods. These methods along with the press operations have not been judged with the concept scoring matrix since there are no alternative methods. The investigated methods are:

- Mesh Image control and adjustment
- Measuring the R- gear housing
- Backlash of the crown wheel
- Pinion preload setting
- Bearing race pressing operations
- Lifting tool
- Pinion Pac
- Transportation

7.1.1 Mesh image control and adjustment

The mesh image, described in chapter 4.2, shows the contact surface between the pinion and the crown wheel and describes the way that they are interacting. It is important to have a good mesh image since this increases the performance, service intervals and lifetime of the central gear. A good interaction between the gear and pinion also keeps the noise level down. The mesh image is mainly affected by the height of the pinion and the axial displacement of the crown wheel. If the mesh image is unsatisfactory it is corrected buy adjusting these factors.

7.1.1.1 Requirements on the method

The method by which the mesh image is controlled should be easy to perform, accurate, robust and reliable. Since cleanliness is important a method which does not use paint or other adhesives is preferable. Since the characteristics of the image vary between different products and since the tolerances are small, a method which does not depend on a workers subjective judgement is necessary. If adjustments need to be made the method should provide an instrument telling the worker, which parameter that has to be adjusted and by how much.

7.1.1.2 Proposals

Proposals	SPS Score
Paint and paper (current method)	3.09
Paint and multiple cameras	3.36
Paint, one camera and robot	**3.80**
Multiple IR- cameras	3.42
IR- camera and robot	3.56

7.1.1.3 Technical description of the "Paint, camera and robot" - method

While still using paint this method uses a CCD camera that registers the patterns on the crown wheel (figure 6.1). The image is then processed with computer software. The software decides if the image is satisfactory or not. If not it tells the operator how much he needs to adjust the parameters (pinion height and axial displacement of the crown wheel) to get the required image. The most crucial thing for this method is that the cameras position is correct and that the lighting is adequate. In order to do this without a large number of cameras the camera is mounted on a robot arm. The robot arm can place the camera in the correct position both for the drive side and back side for all central gear types.

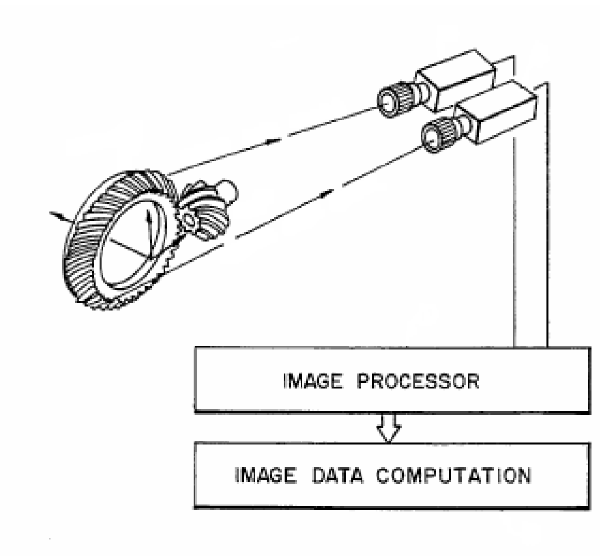


figure 6.1 A pair of CCD cameras and image processing software

7.1.1.4 SPS Analysis

The most rational choice is to use one CCD camera and move it using a robot arm. It scores high in the quality and safety categories. This is because the system allows the operation to become error proof (a gear with poor mesh image cannot leave the plant), and the assessment of mesh image becomes standardised. If the robot is enclosed according to safety regulations, the system is safe. The flexibility is also the highest of all new proposals, as all gears as well as new models can be processed by the robot. Only the current solution can be considered more flexible. The lowest scores are those of process time and investment costs, however all new proposals have a high investment level. While still using contaminating paint, this method provides a higher accuracy since the interpretation of the mesh image is not based on the operators’ knowledge and subjective judgement. It will reduce the number of adjustments needed to one. Not only is an image processing software more accurate and faster than an operator it is less costly and allows gathering statistical information. The construction engineers can use information of these images for future development or adjustments. This method is used today, in a slightly different application, by Gleason, on of the worlds leading gear manufacturers. A similar solution is currently being developed by Svedvision AB where they look for deviations in the pinion surface for Getrag AWD central gears.

7.1.1.5 Investment estimate

This investment will be large since the software is very sophisticated and needs to be adapted to the application. There will also be a lot of development time spent on light setting and the programming of the robot. Svedvision AB estimated the investment cost to 158228 EUR (1500000 SEK), there is however the possibility to use a previously used robot making the investment smaller but development cost a bit higher. The payback time for this solution is 7 years which is the longest for all of our proposals that have a positive NPV. The net present value is 109710 EUR after 10 years. This is low compared to the investment required. However all calculations have been done using step 1 as reference. The result might be better when the production volume increase in step 2 and 3 as scale economics increase the profit. The quality improvement rate estimated by us might vary. The risks of this investment is very high

7.1.2 Measuring the R- gear housing

The gear housing has to be measured in order to select the correct shims for adjusting the pinion height. The measurement should be done between the green and the blue line in figure 6.2. The green line is an imaginary line that runs in between the centres of the bearing caps, herein lie the complication.

7.1.2.1 Demands on the measurement

The measurement needs to be accurate and independent of the operator. It is desirable that the equipment can measure both the R780 and the R660/560 gear housings. It has to be robust and designed for an industrial environment. If the measurement can be done without removing the bearing caps material handling waste is reduced

7.1.2.2 Proposals	SPS Score
Fixture in one bearing cap (current method)	3.21
Fixture in each bearing cap	3.17
Cradle and measuring pens	3.26
Cradle and measuring magnet	3.33
Triangular laser measurement	**3.93**
Laser scan	3.53

7.1.2.3 Technical description of triangular laser measurement

Four separate laser devices measure the positions of the bearing housing seat and the two bearing caps as shown in figure 6.2. The distance between the lasers is known and they are all connected to calculating software. This solution does not require any fixtures except to hold the laser devices in place. The measurement can be made in the assembly line even under slow movement of the gear housing, this movement can be used to find the highest point of the bearing caps. The devises demonstrated to us were two Keyence LKG157:s combined with a controller and software. The LKG157 have a measuring span from 110 to 190 mm which means that both the R560/660 and the R780 gears could be handled without moving the lasers. The resolution of these devises are 0,5 μm which is more than sufficient for our application.

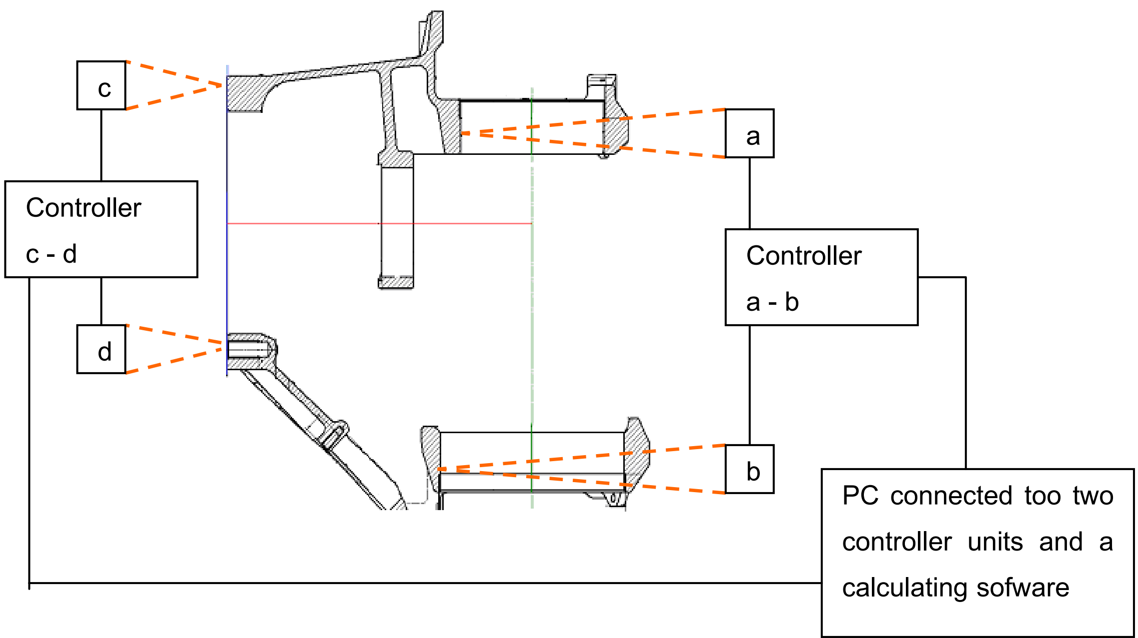


Figure 6.2 placing of triangular lasers

7.1.2.4 SPS Analysis

The most rational option is the triangular laser. It has the shortest process time and the initial investment is relatively low. The results and accuracy that can be achieved are good and only surpassed by the laser scan. The investment cost for the laser scan is enormous and one would have to produce a larger number gears than today in order to motivate this solution. The triangular laser is flexible and does not require large investments or long implementation time.

The method requires that the bearing caps are removed. However it is possible to make measurements with the laser beam inclined the bearing caps would then not have to be removed. Inclined lasers create a new problem of finding the top position of the bearing cap.

7.1.2.5 Investment estimate

The lasers and software will cost 21100 EUR (200000 SEK) according to Fredrik Hallin at Compotech. We then estimate a bit more than the double to build a fixture, calibrate the lasers and software. The payback time is 2 years and the net present value over 100000 EUR. This is 200% of the initial investment over a 10 year period. The assembly time savings can be even greater making this a low risk investment with good profit.

7.1.3 Backlash of the crown wheel

The backlash between the crown wheel and pinion is important for a good gear performance. The material that the crown wheel and pinion are made of expands when operating under normal conditions due to the heat generated by friction in between the teeth. The backlash optimises the fit between the teeth reducing noise, friction and increasing the performance of the gear. The backlash is adjusted turning the adjustment rings in the bearing caps. Preferably the design of the central gear and/or other methods that affect the backlash can eliminate the need to check and adjust the backlash.

7.1.3.1 Requirements for checking the backlash of the crown wheel and pinion

The method used for checking the backlash has to be easy to perform and give a good result every time. The measurement should be easy to perform, give an accurate result which is not dependent on the operator. The backlash is to be measured at three different positions with 120 degree intervals.

7.1.3.2 Proposals SPS Score

Dial gauge on tooth (current method)	3.33
Measuring on the back of the crown wheel	3.68
Rotary encoder on differential housing	**4.18**
Rotary encoder on the differential axis	3.64

7.1.3.3 Rotary encoder placed on the differential housing

A wheel connected to a rotary encoder is placed on the differential housing, see figure 6.3. When the crown wheel is displaced moves the encoder registers the displacement. When the angle is within the tolerance interval it signals to the operator that the end play is correct. The wheel can be rotated indefinitely eliminating the adjustment between two measurements. The encoder is connected to a shock absorber, see figure 6.4, in order to protect it from the hard handling it will experience in production. The shock absorber is connected to the measuring wheel which is the part in contact with the differential housing. A variant of this method is used by the AIM- machine at Arvin Meritor.

7.1.3.4 SPS Analysis

The SPS analysis clearly shows that the best method is the rotary encoder on the differential housing. It scores high both in safety and quality. It will eliminate operator influence on the results, and the procedure becomes standardised. The method is also an enabler of error proofing. The process time is short, there is no need for resetting the gauge. This method would reduce the time for setting the end play by approximately 30 seconds or more. The drawback is that the radius ratio between the differential housing and the measuring wheel can amplify eventual measurement errors. This requires further investigation. The translation of today's displacement to number of pulses registered by the rotary encoder also needs to be done.

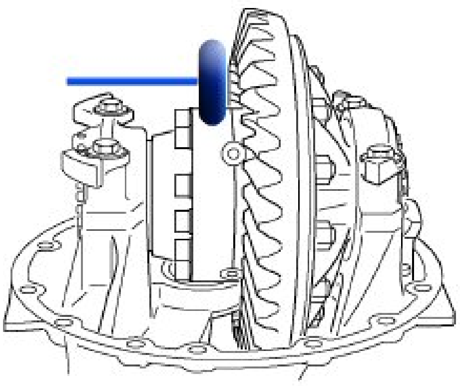


Figure 6.3 Placing of encoder

figure 6.4 Encoder, shock absorber and wheel

7.1.3.5 Investment estimate

The equipment cost is 1582 EUR (15000 SEK) and we estimate the installation and programming investment to be three times as large. The payback time is one year and the net present value is 41797 EUR. The pay back time is one year and after 10 years the investment will have paid itself of 6 times over. Even after 5 years the profits are good compared to the size of the investment. The risk and the investment levels are very low.

7.1.4 Pinion preload setting

As described in chapter 4.3 it is important that bearings have an adequate preload in order to function properly.

7.1.4.1 Requirements on method for preloading pinion bearings

The bearing preload should be set correctly every time. The method can be performed with the gear in line, i.e. in the main flow. The method allows preload to be set within the takt time for capacity step 3. The method enables the operator to work with good ergonomics all the time during setting of preload. The method is flexible to fit in a single line for all central gear models.

7.1.4.2 Proposals	**SPS Score**
Current method	2.83
Projecta Set	**3.88**
Temper Smart Press	3.76
Individual measurement	3.18

7.1.4.3 Projecta set by TIMKEN

The pinion is partially assembled, that is to say, assembled to the extent that the pinion shaft extends through the gear/bearing housing. Three of four bearing components are installed, i.e. all bearing components except the cup for the front bearing (figure 6.5). This cup is placed in the gauge. The gauge has a male and a female part, the bearing cup is placed in the female part. The male part has a tapered surface which conforms with the surface of the front bearing race. When fitted, the male part seats perfectly against the front bearing race. The gauge is clamped against the assembly, and the pinion is rotated. Rotation ensures that the bearings are seated properly. In the gauge there is a spring, and the gauge measures the distance *b* the female part has moved against the male part. As the distance *a* of the intervening part is known, the shim thickness *c* can be calculated by $c=a-b+p-i$. In this formula *i* is the change in axial dimension due to the interference fitting of the front bearing cup. *p* is the preload expressed in a distance.

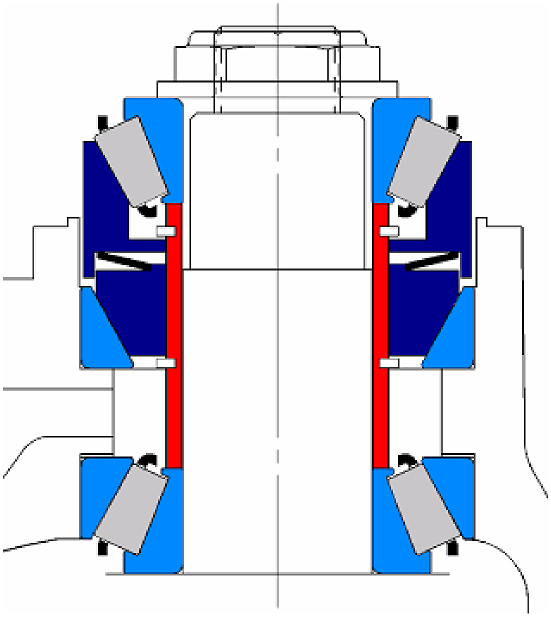


Figure 6.5 Placing of the measuring gauge in gear housing

7.1.4.4 SPS Analysis

The analysis shows that the Projecta Set is the best investment. The safety and quality scores are high. The Temper Smart press scores even higher in these sections but due to the need of adjustable spacers the investment will be too large. The method results in an accurate measurement of required shim thickness. This is due to the fact that all parts except the front bearing are assembled as the measurement is done, i.e. most interference fits are taken into account. Furthermore, measurement is performed with the bearings under load and rotation to simulate normal working conditions, which increases accuracy. As a result, the bearing preload can be set accurately, i.e. higher quality is achieved, and waste of rework is minimized.

7.1.4.5 Investment estimate

Semiautomatic Projecta Set equipment will cost a little bit over 100000 EUR to develop and install (Wettenskog and Russell of TIMKEN). The payback time is 3 years and the net present value is 200332 EUR. The relatively high profit opportunity compensates the long payback time. And there will be a clear improvement in quality and performance improving the Scania brand in total. This cannot be included in the calculations since it is almost impossible to estimate. The risk is medium. Switching to TIMKEN bearings would reduce the development cost of the equipment since they would not have to be customised.

7.1.5 Bearing race press operations

The bearings and the bearing races in the central gear must be assembled using presses. In figures 6.6 – 6.8 the blue arrows indicate where the races are to be fitted.

Figure 6.6 R- bearing housing

Figure 6.7 RP- gear housing

Figure 6.8 RBP- gear housing

7.1.5.1 Requirements on the method

The press operation is monitored, i.e. it is ensured that an article is pressed to the correct depth and with a correct force (normally 200kN), and the article ends up correctly positioned (not tilted etc.). The press does not damage the article or the assembly to which the article is being pressed. The performance is constant from operation to operation. The operation is safe and the operator cannot get injured.

7.1.5.2 Proposals

Double press

Pulling press for input shaft

7.1.5.3 Double press for pinion bearing races

To press the bearing races for the pinion into the gear housing, a “double-press” can be used. The press has fixed pressing tool with a cylinder through the centre (figure 6.9). At the end of the cylinder there is a coupling for attaching another pressing tool (figure 6.10), facing the first one. The press is inserted through the gear housing. Then the second pressing tool is attached. As the cylinder retracts, the pressing tools are forced closer together, and the races are pressed into position. The press cylinder is hydraulic, and has a measuring device measuring how far the cylinder retracts.

figure 6.9 double cylinder

figure 6.10 double tool

figure 6.11 Pulling cylinder

This method saves time as two pressing operations can be performed at once. It also has the advantage that the gear housing need not be turned between pressing of the races, which saves time and eliminates the need for handling equipment to turn the gear. Dependent on how the cylinder and gear housing is positioned during the operation, other assembly operations can be performed with the gear housing still positioned in the press, as there is no obstructing equipment.

Disadvantages: Two pressing operations performed in one operation makes the operation difficult to monitor. The conveyor/carrier used to transport the bearing must be reinforced.

7.1.5.4 Pulling press

This device pulls the pressing tool against a bearing race, instead of pressing from above as conventional presses. The pulling operation is conducted by a piston, which is inserted from beneath, through the hole for the pinion in the gear housing (figure 6.11). The pressing tool is attached to the piston with a simple coupling, which makes it flexible to use pressing tools of different shapes and sizes. The piston pulls the pressing tool against the race which is then pressed into position. The gear housing's position is fixed during the whole operation. The press cylinder is hydraulic, and has a measuring device measuring how far the cylinder retracts

The method eliminates the need for positioning (turning) the gear house for pressing races, eliminating handling equipment and saves time. The press operation can be performed with the gear housing in the main assembly line, however it is required that the conveyor/carrier for the central gear is reinforced to withstand the force of the press. Since the press is situated under the gear housing, there is space and no obstructing equipment which allows other assembly operations to be performed at the same position.

7.1.6 Lifting tool

The lifting tool we saw when visiting Arvin Meritor (figure 6.12 & 6.13). It is fastened on the pinion to lift the gear housing and pinion. It is a smart and simple solution which saves about 5 seconds each time it is fastened and released. The lifting tool can be resembled with a chuck for a drill. In total this sums up to 30 seconds of assembly time compared to the threaded tool used today. In addition the ergonomic situation for the workers will improve giving the method another positive aspect

Figure 6.12 Lifting tool

Figure 6.13 Lifting tool

7.1.6.1 Investment estimate

It is not hard to motivate this investment. The payback time is one year and after ten years the investment will have paid itself of eight times over. Both the risk and the investment levels are low and the tool can be developed and manufactured by Scania

7.1.7 Pinion Pac

Timken deliveries bearing housings (called Pinion Pac) complete with bearings, races and sealing ring (figure 6.14). The bearings are preloaded when delivered and the pinion can be pressed into the Pinion Pac. A soon as the pinion has been mounted in the Pinion Pac the package can be assembled to the gear housing. The Pinion Pac is currently used by Arvin Meritor (figure 6.15). A similar product, produced by SKF, is used for the wheel hubs in Scania front axles.

7.1.7.1 Analysis

The Pinion Pac would be applicable on the R- gears but not on the RP, RB and RBP gears. The product would eliminate many operations in the central gear assembly and raise the quality and performance of the central gear, as the races are grinded by Timken when positioned in the bearing housing. The Pinion pack replaces the bearing housing, the pinion’s bearings and races as well as the sealing ring and associated assembly operations. The Pinion Pac must be customised to Scania's gears in order to work properly.

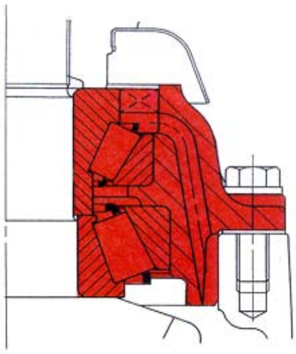


Figure 6.14 Components of the Pinion Pac

Figure 6.15 Pinion Pac used by Arvin Meritor

7.1.7.2 Investment estimate

The calculations clearly show that the Pinion Pac is too expensive to be implemented. The purchase price is the double of today and the savings in time and quality do not compensate this difference. If the material handling and inventory costs were taken in to consideration the result might improve a bit. Since the Pinion Pac would eliminate the need of sequencing software and facilitate the assembly line layout it might be profitable in the end but this requires further investigation.

7.1.8 Transportation of the gear in the main assembly line

The central gear has to be transported downstream in the assembly line. To do this some form of transportation system is needed. There are many different types of systems, from simple rolling systems where the central gears are pushed forward by manual power to advanced flexible systems where the central gear is suspended in a fixture which allows it to be rotated 360 degrees in all directions, lowered, elevated, stopped, accelerated, separated from the main flow etc. There is also the possibility to transport it on AGV:s which is the case at the Scania engine assembly in Södertälje, Sweden. The choice of conveyer system is, as always, a trade off between cost, efficiency and ergonomics. We have chosen to evaluate the different transportation proposals just as we did with the methods using the SPS method concept scoring matrix.

7.1.8.1 Demands on the transportation

The system must in no way limit the production capacity or reduce the quality of the final product. It must be safe and simple to use and allow good ergonomics and working positions for the assembly personnel. Lifting, turning, pulling and pushing movements should be kept to a minimum. Low energy consumption is always desirable. The transportation system allows all assembly operations to be performed in the flow.

7.1.8.2 Proposals	SPS score
Mech rolling conveyor (current system)	2.68
MAN rolling conveyor	3.34
Motor driven rolling conveyor	**3.62**
Push carts	3.22
AGV	3.37
Roof driven conveyor	3.41
Floor driven conveyor	2.58

7.1.8.3 Motor driver rolling conveyor

The gear housing is fastened in a fixture that has four small wheels. These wheels run on two rails on each side. The fixtures are motor driven. The solution facilitates turning of the gear. It is a combination of the MAN rolling conveyor and the floor driven conveyor (described in Attachment I).

7.1.8.4 SPS Analysis

Our analysis of these proposals shows that the motor driven rolling conveyor is the proposal that best enables an assembly line fulfilling the principles and philosophies of SPS. It has the shortest process time of all proposals, as all assembly operations can be performed as the central gear is in the conveyor. The accident risk is low as the conveyor hinders operators to come in between central gears in the flow. It has the lowest investment level of all the automated solutions. The drawbacks are its limited flexibility and poor ergonomics, especially due to the limitations in adjusting the working height. The ergonomic situation will still be better then today since the current assembly lines all have the limitation in working height but since the CVX lines are not motor driven the products have to be pushed manually downstream. This pushing is eliminated with the new transportation system.

Although driven by a motor of some kind purely mechanical solutions for turning or lifting the product can be used. This keeps the technology level, maintenance costs and initial investments down. With a driven system it is easier to maintain a strict and constant takt time, the operators can “feel” the takt. The equipment has the same drawbacks as the floor conveyor and the mechanical rollers in that it occupies floor space and a worker cannot change sides unless a special passage is constructed. A variant of this system is used by Arvin Meritor today (figure C.3 in attachment C).

Figure 6.17 MAN gear fixture

Figure 6.18 R- gear housing

7.1.8.5 Fixture for the gears

One problem still remains regarding transportation. All central gears have different gear housing measurements (except R560 and R660 which have the same). This complicates things since we either need one flexible complex fixture for all gears or one fixture for each gears type. In addition, the R- gears need a fixture which can first transport only the bearing housing and then the gear housing or alternatively two separate fixtures., see figure 6.6 for bearing housing and figure 6.18 for gear housing. We have not investigated this issue in detail but we would suggest one fixture for each gear type since this solution will be robust, relatively cheap, quick to implement and easier for the workers to handle. The fixtures used by MAN are very interesting since our transportation system will resemble what they use in many aspects, see figure 6.17.

7.2 Summary of the product benchmarking

In this summary we will discuss the differences between the different central gears that we have investigated. All the differences between the gears are described in attachments E and F. Basically one can divide the gear into two major groups; those designed for automatic assembly (Mercedes, Getrag and Toyota) and those designed for manual assembly (Arvin Meritor, MAN and Scania). The first group are gears produced in high volumes and the design is focused on saving assembly time and facilitating automatic assembly. They all use collapsible sleeves to set the pinion preload. Collapsible sleeves consume less assembly time then ordinary shims but they make it more difficult to assure a correct preload and locking nut torque. Another difference between the two groups is the support bearing which all the gears in the manual group have. The reasons for not having a support bearing might not only be to rationalize the assembly process. The Getrag and Toyota gears are not subjected to the great stresses that the other gears are and they therefore might not need to compensate for this. However, when looking at the Mercedes gear it is obvious that the bearings and pinion are over dimensioned to compensate for these stresses. The last difference between the two groups is the bearing housing which is only present in the manual group.

When comparing the CV central gears one sees that the Arvin Meritor is the one most similar to the Scania R- gears. The Arvin Meritor gears are a bit more robust in all aspects. The MAN gears are more modern than the Arvin Meritor and Scania gears, they have small holes in different places to reduce weight and the differential housing and crown wheel are joined together with the same bolts, see attachment E.2. As mentioned before the Mercedes gears are designed for automatic assembly and in addition to the differences described earlier Mercedes have also integrated one differential housing half with the crown wheel reducing assembly time even more.

An important aspect is the number of parts that the different gears have. The number of parts has a great impact on assembly time and quality of products. Table 6.2 shows the total number of parts of all benchmarked items, in attachment G a more detailed table is displayed.

		Scania R780	**Scania R660**	**Arvin Meritor RS**	**MAN HY 1133**	**MAN HY 1350**	**Mercedes HL6**	**Mercedes HL8**	**Toyota land Cruiser**	**Getrag High Torque**
Complete Gear	Components	43	42	38	42	37	39	42	43	24
	Screws	45	39	45	30	31	23	28	24	11
	Bearings	5	5	5	5	5	4	4	4	4
	Total	**93**	**86**	**88**	**77**	**73**	**66**	**74**	**71**	**39**

Table 6.2 Number of parts

The table clearly shows that the central gears of Scania are the most complaw along with the Arvin Meritor gear. Not very surprisingly the Getrag gear is the one with the lowest number of parts.

All gears investigated have a straight differential lock parallel to the differential axis except the Getrag gear which does not have a differential lock. In figures 6.27- 6.30 one can see how this makes the Scania differential lock more complex compared to the others.

7.3 DFAA- analysis of today's central gears

The detailed results of the analysis are to complex and detailed to be described here and therefore we will summarize the most important findings and conclusions from our DFA-analysis in this chapter. The detailed results are displayed in attachment H.

- A common problem for all the central gears is the number of parts that need to be assembled is large. This problem can be solved since the analysis shows that many components can be integrated or eliminated all together.
- There are parts that are neither symmetrical nor distinctly asymmetrical, which in many cases can be solved by redesigning the part to some extent.
- There are many assembly directions, which creates a need for repositioning the central gear in fixtures or performing assembly operations from inappropriate directions.
- There is limited space for assembling some parts, and in addition special tools (e.g. pliers, hammer and press) are needed to fasten some parts.

7.4 Product alterations

In this chapter we present the different product alterations that we have generated through the DFAA- analysis, benchmarking studies and patent searching. For each alteration a short technical description is given followed by an analysis of the advantages and disadvantages. Since these changes require a redesign of the gear it has been very difficult for us to estimate the investment levels. These estimations need to be done by the NAX- department who are responsible for the design of the products. We have therefore decided not to do any investment estimates and just settled for dividing the alterations into three groups; Short-term, long term and next generation alteration. These groups are presented in chapter 7.3.2. We have not used any SPS analysis or any other similar method to judge the different proposals since there is only one or two proposals per problem. Therefore each proposal is explained and the analysed. The chosen proposals are shown in chapter 7.3.2.

7.4.1 Steering pins in the input shaft differential

In the input shaft differential the differential spider is fitted in a ring. Today there are four steering pins that must be pressed into the differential housing and then into the differential spider, see figure 6.19. The operator must use a hammer and a fixture (figure 6.20) to fit the pins in the holes. The pins keep the differential spider in position. However it is possible to design a differential ring where no pins are needed. The reason for that design is not used is that the differential housing without pins is a patent belonging to Volvo. This patent is dated January 11th 1983 (Swedish patent 8300100 B). This means it has expired, hence Scania should be able to use the pin-free differential housing design in their central gears.

Analysis

Eliminating the pins will reduce assembly time by 2 minutes for the bogie gears. It will reduce the number of parts to assemble and less material handling will be needed. The working environment will be safer as there will be no need to use a hammer or fixture to assemble the pins. There are no large investment costs and manufacturing costs will be reduced. If the pins are to be eliminated, it is necessary to design the differential housing so the differential spider stays in place during operation of the gear.

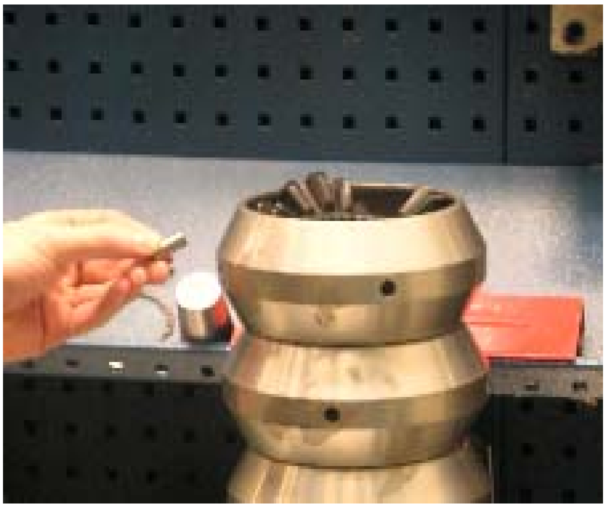


Figure 6.19 Steering pin and differential rings

Figure 6.20 assembly fixture

7.4.2 Chamfers for washers

Washers are positioned on front cover and the sealing seat. The operator must position the washers so they match the holes for the screws. Chamfers in the front cover and sealing seat facilitates positioning and enables the washers to stay in position before screws are inserted, as illustrated in figure 6.21. This product alteration proposal was generated by the DFAA-analysis, which showed that guidance is needed for the positioning of washers.

Analysis

Creating chamfers will reduce assembly time by approximately 5 seconds.

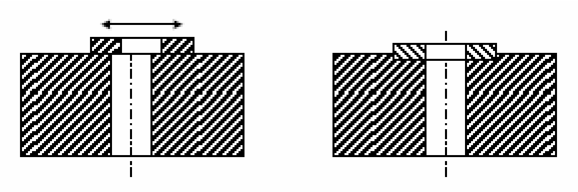


Figure 6.21 Positioning of washers with and without chamfers.

7.4.3 Integrating washers with screws

As shown by the DFAA-analysis, integrating washers with screws would eliminate all washers and the positioning of them. An alternative to integrating the washers with the screws is to have the supplier deliver screws with washers already assembled, or investing in a machine that puts washers on the screws.

Analysis

The bearing housing or Pinion Pac (see 5.4.10) assembly is reduced by 25 seconds and the front cover assembly for the bogie gears is reduced by 37 seconds. In addition there will be less material handling and errors related to missing washers will be eliminated. This product alteration can be quickly implemented, and is superior to the proposal of creating chamfers for the washers, which in comparison results in a small time saving.

7.4.4 Screw for adjusting differential lock

The play between the differential coupling halves can be adjusted by controlling the length of the piston stroke in the differential manoeuvring unit, figure 6.22. The piston’s stroke is adjusted with a screw, stopping the piston at a certain point. The screw is positioned in the lid of the differential manoeuvring unit, which has a threaded hole for the screw.

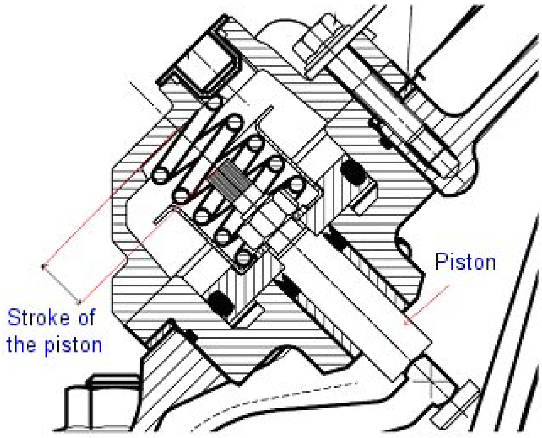


Figure 6.22. The differential manoeuvring unit with the stroke of the piston indicated.

Analysis

This design makes the shims used today to adjust the play between the coupling halves redundant. As a result, there will no longer be any need of keeping shims of different thickness, and foremost the adjustment of the play between the differential coupling halves can be done in an efficient manner. Today adjusting the shims means that the entire differential manoeuvring unit must be disassembled from the gear housing using a screw driving machine. With a screw for differential lock adjustment 25 seconds is saved when assembling the axle differential lock, and 60 seconds for the bogie differential lock. The amount of rework would also be reduced by approximately 30-40%. This product alteration is necessary if the central gears are to be assembled in a takted flow, where adjustment must be quickly and easily done, i.e. this proposal is supported by the principles in SPS.

7.4.5 Adjustable spacer

The adjustable spacer in figure 6.23 is meant to replace the solid spacer and the shim between the tapered bearings for the pinion. The spacer deforms plastically when it is subject to a force. This property allows the spacer to be adjusted, i.e. the height of the spacer can be adjusted very accurately by applying a load to the spacer.

With this spacer it is no longer necessary to keep inventory of spacers and shims of different thickness. The main benefit with the adjustable spacer is that measurement of proper spacer height and adjustment of the same can be executed at the same time, with a special purpose machine, the Temper Smart Press, described in attachment I. Additionally, the spacer is adjusted when positioned in the gear, i.e. after the spacer has been adjusted the front bearing for the pinion can be assembled directly. This approach is faster than the equivalent method today. With the adjustable spacer, it is no longer necessary for the operator to countermeasure shim thickness and moreover the wrong shim cannot be picked as the operator is excluded from this process. The adjustable spacer is very similar to the collapsible sleeve used by Getrag, Mercedes and Toyota. The concept is the same but adjustable spacers in combination with an adequate assembly method allows controlling the locking nut torque, which is not possible with the collapsible sleeve.

Figure 6.23 Adjustable spacers from temper corp.

Analysis

The adjustable spacer we have studied is supplied by Temper Corporation. The spacer is designed to deform plastically under a load three times the bearing preload. This means that the spacer cannot deform further during normal operation of the gear. The spacer is used e.g. in truck wheel hubs. The spacer has to be designed specifically to Scania's gears in order to function properly. For 1165 EUR (3329 USD) per model, Temper Corporation supplies around 20 prototypes and equipment for installing the spacers (Ash). The time savings is approximately 140 seconds per central gear. The adjustable spacer and belonging setting equipment from Temper is an interesting solution, however our calculations shows that it is not profitable. An alternative is that Scania develop own collapsible spacers, which may prove to be profitable.

7.4.6 X-configuration of pinion bearings

Placing the tapered roller bearings for the pinion in an X-configuration as shown in figure 6.24 (as opposed to the O-configuration that the bearings have in Scania's central gears today, figure 6.25), will make it feasible to eliminate the support bearing at the top of the pinion. By placing the rear bearing where the support bearing is placed today, the rear bearing will fill the support bearings function as well as its previous function (i.e. bearing the load exerted by the pinion). This solution is explained more thoroughly in patents "US6200241 B1 2001" and "JP2003301932 2003".

Analysis

Fewer parts and assembly operations are needed in comparison with today's design. A total of 25 seconds of assembly time will be eliminated. This solution requires a significant re-design of the gear housing and the bearing housing, and the bearings must be dimensioned to withstand the new forces.

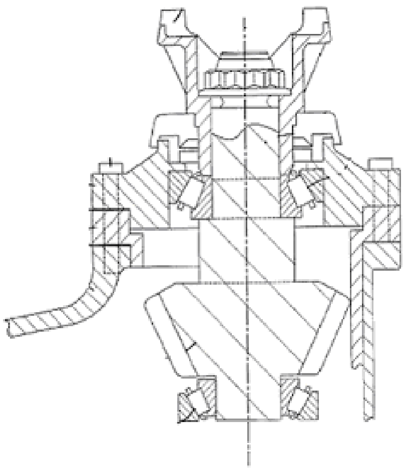


Figure 6.24 Pinion bearings in an X- Configuration. The support bearing is no longer necessary.

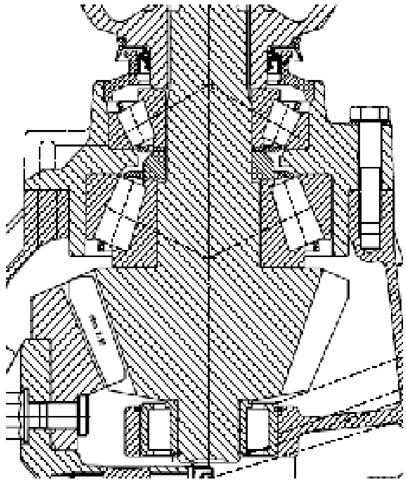


Figure 6.25 Bearings in O- configuration and support bearing

7.4.7 Two-piece Bearing Housing

The bearing house is split in two pieces, figure 6.24. The first half of the bearing housing supports the front tapered roller bearing, the second half supports the back tapered roller bearing. The first half is adjacent to the end yoke and the second half is adjacent to the pinion gear. In an alternative design, the first half of the bearing housing is threaded to the second half of the bearing housing (figure 6.26).

Analysis

With a bearing housing split in two pieces, shims for preloading can be placed between the bearing housing halves instead of placing the shim on the pinion, i.e. preload is set by an external shim. See Figure 6.24. This makes adjustment of preload considerably less complicated in comparison with today, as the front bearing does not have to be disassembled (i.e. pressed of) when changing a shim. Furthermore, the same shims can be used to set the preload and adjust the pinion height. This design will result in that the preload can be adjusted quicker than today in the case of erroneous preload. A prerequisite for changing preload shims without pressing off the bearing is that the bearings are in an X-configuration.

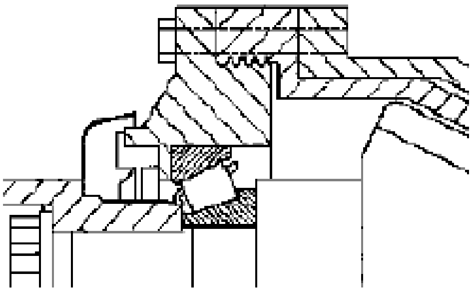


figure 6.26 threaded bearing housing

The alternative design (threaded half) would make shims for preloading redundant, as preload can be set by screwing the first half into the second half, and thereby applying pressure to the bearings.

7.4.8 Integrating crown wheel with differential housing half

This product alteration proposal is based on the DFAA-analysis, where the crown wheel scored low in the integration/elimination question. Integrating the crown wheel with one of the differential housing halves and the differential lock coupling half means that three parts becomes one. This solution is used by Mercedes today, see attachment E.3.

Analysis

In total 12-16 bolts and nuts and associated assembly operations screwing, pressing, handling and storing are no longer needed with this design. As a result 287 seconds of assembly time can be eliminated.

7.4.9 Same bolts for the crown wheel and differential housing

An alternative to the previous proposal is to utilize the screw union for joining the differential housing halves to fasten the crown wheel to the differential housing. This design is implemented by MAN and can be seen in attachment E.2.

Analysis

This design would eliminate the 12-16 bolts for the crown wheel, and preferably also corresponding nuts. The design increases the requirement of the screw union’s strength. A stronger screw union means that more and larger bolts are needed, therefore the total saving of assembly time will not be as extensive as when integrating the crown wheel with the differential housing. Therefore, in an assembly point of view, the proposal of integrating the crown wheel with the differential housing half is superior to this proposal.

7.4.10 Integrating differential lock manoeuvring unit with gear housing

This product alteration means that the function of the lower lid for the differential manoeuvring unit is taken by the gear housing instead. The upper lid remains, but cylinder and piston are placed in the gear housing. This possibility was pointed out in the DFAA-analysis. This design is used by many of Scania’s competitors see figures 6.27- 6.30

Figure 6.27 Differential lock Arvin Meritor

Figure 6.28 Differential lock MAN

Figure 6.29 Differential lock Mercedes

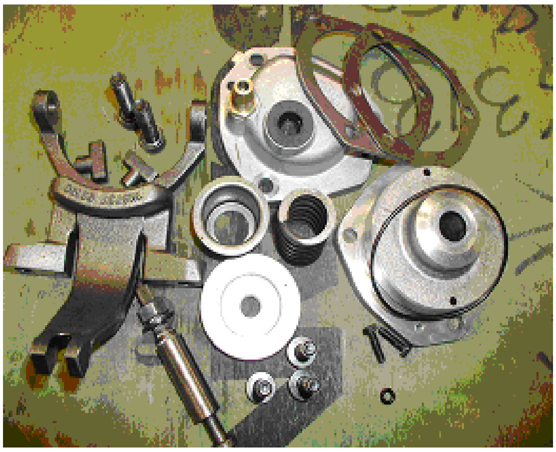


Figure 6.30 Differential lock Scania

Analysis

The design results in that the number of parts in the differential lock can be lowered drastically (how much is dependent on the design). An integrated differential lock can be assembled directly to the gear housing (the base object), i.e. no pre-assembly is needed. This approach is supported by the principles in lean manufacturing (REF SPS) and DFAA (Eskilander 2001). The design requires a redesign of the gear housing as there is lack of space today. Hence, this proposal should be considered in the design of gears in the future.

7.4.11 Oil filter RB662

The oil filter for RB662 has 15 articles and 9 different article numbers. This is to be compared with the oil filter for RBP835/735, which has 3 articles and 3 article numbers. See figure 6.31. The function is however the same.

Analysis

If the design of the RB662 oil filter would resemble the design for RBP835/735, articles and associated assembly could be eliminated saving time and facilitating line balancing in an assembly line for all gears. The number of assembly directions would also be reduced. These issues were pointed out as problems in the DFAA-analysis.

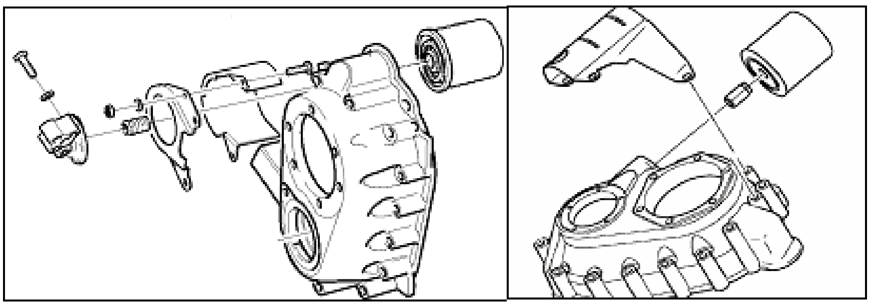


Figure 6.31. The oil filter for RB662 (left) and for RBP835/735 (right).

7.4.12 Straight lever for the differential lock

Today Scania’s central gear has a lever that must be attached with screws to the gear housing. With a straight lever many advantages are gained, as it does not have to be attached to the gear house. Also, as a straight lever has no pivoting point, which means that adjustments done at the manoeuvring unit (e.g. with shims) is directly connected to the play between the differential lock coupling halves.

Analysis

A straight lever for the differential lock would solve many of the problems pointed out in the DFAA-analysis. There is no need for fork studs that can pivot. Instead, the fork studs can be integrated with the lever. In total, a straight lever design makes one bracket, 2 screws, one shaft and two fork pins redundant. A straight lever is also a symmetric article that can be positioned in more than one way. The adjustment of the differential lock is simplified. Eliminating the screwing operation when attaching today's lever to the gear housing saves approximate 20 seconds of assembly time. To fit the straight lever a part of the gear housing and the axle itself must be altered as the position of the break system is hindering this design. Therefore this proposal should be considered when designing gears and axles in the future, and is not interesting for the current central gears.

7.4.13 Threaded lid to the input shaft

If the sealing seat for the bogie gears is threaded (see red circle in figure 6.32), with matching threads in the gear housing, the input shaft's bearings can be preloaded in a rational manner. By rotating the sealing house clockwise the sealing seat is screwed tighter against the bearing, increasing the preload. When required preload is set, a locking mechanism secures the sealing seat to the gear housing. This construction would make it feasible to measure the input shaft's end play, and directly afterwards set preload by screwing the sealing seat a given number of revolutions, based on the incline of the threads.

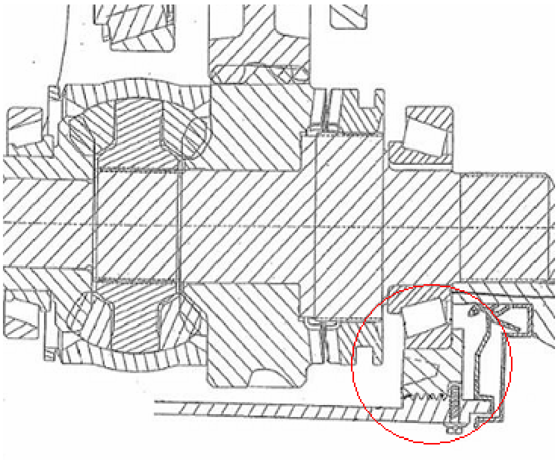


Figure 6.32 threaded input shaft cover

Analysis

With this design and a rational assembly method approximate 5 minutes of assembly time would be eliminated, as many of the operations needed to check the end play and assembling/disassembling the sealing seat is eliminated. Furthermore, no shims would be needed nor storage of shims of different thickness. As this proposal requires extensive development and testing before it can be implemented, our suggestion is that this proposal should be considered in the development of future gears.

7.4.14 Adjustable shim for the input shaft

The idea of this product alteration is to replace the shims for preloading the input shaft with an adjustable shim see figures 6.33 and 6.34. The thickness of the adjustable shim is increased when its top ring is rotated in one direction. It cannot be rotated in the opposite direction due to locking teeth in the shim rings. This design is used by General Motors. The advantage of using an adjustable shim is that a rational assembly method can be used. Instead of removing the sealing seat, picking shims of the right thickness, measuring the shim package and placing them on the bearing race which is the work procedure today, the following method is used: the shim is placed on the race before it is pressed in placed. The spindle then presses the race and shim in place, without being removed the spindle rotates the shaft and measures the end play. While doing this it rotates the top shim ring until the end play is zero. It then rotates the top ring a given angle increasing its thickness another 0,2 mm.

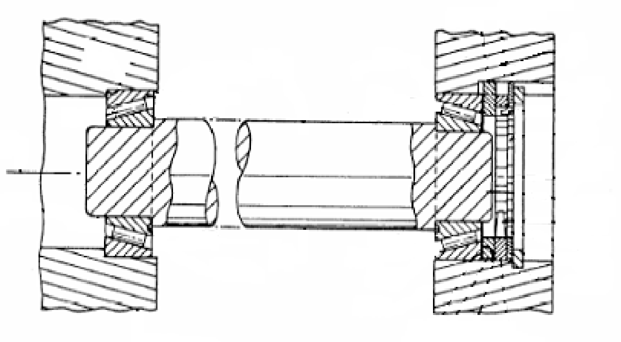


figure 6.33 Adjustable shim on the right bearing

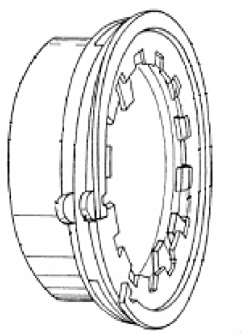


figure 6.34 Adjustable shim

Analysis

This alteration would need new assembly equipment and a quite large re- design of the gear but the time savings could be up to 300 seconds for each bogie gear.

7.4.15 Conical gear set manufactured with a grinding method.

Today the conical gear set is manufactured with a lapping method, which results in that the pinion and crown wheel are paired together. In addition the shape of each gear tooth varies from tooth to tooth. This is why the gear mesh image and gear end play must be checked at three different points when assembling the gear. Manufacturing the conical gear set with a grinding method results in that each tooth is identical. Getrag, Mercedes and Toyota use grinded gear sets.

Analysis

This product alteration results in that mesh image and gear end play need to be measured at one point only. Furthermore, there is no longer a need for pairing the pinion and the crown wheel. This facilitates material handling to the assembly line and eliminates checking the pinion and crown wheel's manufacturing numbers for agreement. Our conclusion is that a conical gear set manufactured with the grinding method is better in an assembly point of view than gear sets manufactured with the lapping method.

7.4.16 Integrating coupling half with differential housing half.

As shown by the DFAA-analysis, it is possible to integrate the coupling half for the differential lock with the differential housing half. The RBP835/735 gears already have this design.

Analysis

Integrating the coupling half does not reduce the number of parts, as the coupling half is integrated with differential gear. However this product alteration would mean that the same differential gears and coupling halves can be used in all central gear models. As this requires redesigning the differential it should be considered in the development of future gears, and not of immediate importance.

7.5 Assembly line floor

The assembly line floor is today made of concrete with rubber sections where the operators are standing. According to the assembly workers the concrete floor is too hard to work on. The rubber sections are soft but the foot easily gets stuck when a foot is turned creating stresses on the joints and muscles. A solution to this is parquet flooring (figure 6.35).

This type of floor is softer than concrete but has less friction then rubber. It is visually more appealing than concrete or rubber since it has a neutral and less sterile colour. It is easy to install and exchange as it can be cut and shaped using a normal pocket knife. It is easy to clean and the cost is low. This type of floor has been laid on the wheel hub and front axle assembly lines and the response from the operators has been very good (Hedvall 2005). The cost of the floor was 10549 EUR (100000 SEK) (it is assumed that approximate that the same floor area is required for the central gear line) and it was laid by the assembly personnel themselves.

figure 6.35 parquet flooring

7.6 Assembly line layout

We have worked with three different philosophies in our layout. We have designed one straight line, denominated “v5”, were all gears are transported through the same working stations in a strict one piece flow. The second line concept is called “bogie cell”, were the differential assembly and many bogie gear operations have been placed on separate lines or production cells connected to the main assembly line. This is done to eliminate waiting waste and shorten the throughput time. Finally a proposal using the Pinion Pac is described. This proposal is basically the same as the bogie cell layout but the Pinion Pac allows for the bogie cell to become a separate line giving the final assembly line a “Y” formation. These three layouts are presented in attachment P. In order for the reader to get a better understanding of these layouts we provide a GANT- diagram in figure 6.36 with an amplification in attachment O.1. This diagram show the necessary predecessor of each operation group and the posterioir operations needed to obtain a finished product. Another way to looka at it is that the square which reads Alpha are the incoming raw material and the square Omega is the finished product.

When designing the layout it is important that the central gears leave the assembly line in the same sequence as they are to be used at the rear axle assembly line. This enables a reduction of central gear inventory, material handling and transportation which are fundamental goal of SPS, see chapter 3.2.4. At the same time it is important to have a levelled flow in order not to overload the assembly line workers.

The rear axle assembly line has many different products and the sequence in which they are produced is decided by the final vehicle assembly in Södertälje or Zwolle. This means that the central gear production sequence can be considered random with the restriction that a bogie gear is always accompanied by its corresponding single gear (RBP735 is followed by a RP735 and so forth), except when producing spare parts.

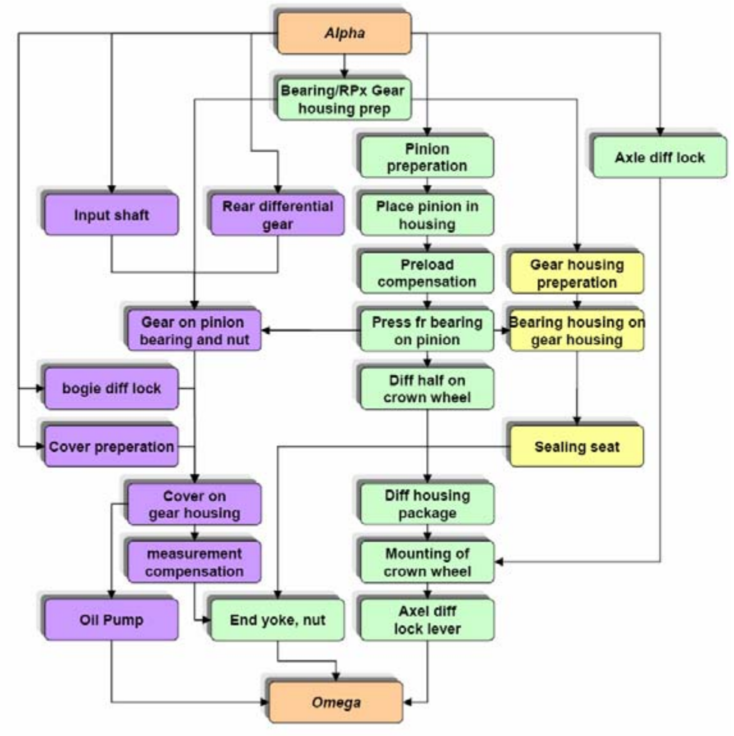


Figure 6.36 GANT- diagram of the different groups of operations

7.6.1 Assembly line layout v5

The layout "v5" is based on the similarities between the different types of gears (single and bogie gears). Each assembly operation needed to assemble each type of gear was studied and compared. Any differences were meant to be solved by alternative tasks for the operator and use of andon resources. Another idea behind this layout was that no parts were to be assembled until truly needed, for reasons of cleanliness. The assembly sequence is formed to minimise handling of the gear housing, i.e. the number of times the gear housing must be turned as assembly must be performed from several directions.

The v5 – layout has the advantage that FIFO (First In First Out) can be implemented, the gears can be assembled in the same sequence as the assembly of axles. The main disadvantage is that without a very large number of andon resources it is impossible to balance a line with this layout without a large amount of waiting waste. This is due to the fact that the bogie type gears have parts that need to be assembled which takes far too long to ever be assembled in the same flow as the single type gears. A line with this layout would result in that the operators at many positions either have very little to do or are overloaded with work during each takt, dependent on the type of gear that is to be assembled. In many cases using an andon resource is not a solution to this problem, as there is a strict assembly sequence, some operations simply cannot be performed until other parts have been assembled.

7.6.2 Assembly line layout Bogie Cell

The bogie cell layout was formed as it became obvious to us that a single unbroken flow for all assembly gears creates waste as described in the previous chapter. To solve this problem we chose to use variants stations for the bogie gears in order to create a levelled flow, as supported by SPS. Variant stations mean that one worker perform one set of operation when working on one type of product and another set of operation when working on a different type of product. Even though the operations are different they are done at the same working station. Cleanliness is addressed in the design of the flow, as no parts are assembled until they truly need to be and the line has a one piece, levelled flow. A flow diagram of the layout can be seen in attachment O.2 and in smaller scale in figure 6.37

The main line layout is focused on the assembly operations for the R- gears because these form the majority of the central gears produced. The main line is represented by the largest grey arrow in figure 6.37. As most of the variant stations for the bogie gears end up in sequence, they form an alternative flow (The red arrow surrounded by purple blocks). This flow is U-shaped to form a cell in order to have a good visual flow over the bogie assembly. The alternative flow for bogie gears creates the need for an internal sequence in the line. The internal sequence ensures that not only the main flow but also the cell for the bogie gears can have a constant takt.

The bogie gears must arrive with a fixed interval to the assembly cell for bogie gears (In step 1 every 7th gear is a bogie gear). Without this levelled flow of gear types the operators in the cell may be either idle or overloaded with work. A constant interval between product arrivals creates a levelled and controllable flow. The internal sequence is controlled by a computer that optimises the balance between the products. When the two flows later are joined again there is a buffer (purple and white block in figure 6.37) for the bogie- gears, which enables the gears to have a synchronised output sequence with the rear axle assembly.

In this layout proposal it is necessary to separate the pinion and crown wheel. It must be ensured that the pinion and crown wheel match each other in the completed central gear, therefore these two components need to be sequenced. If the conical gear set is manufactured using a grinding method this sequence is no longer necessary.

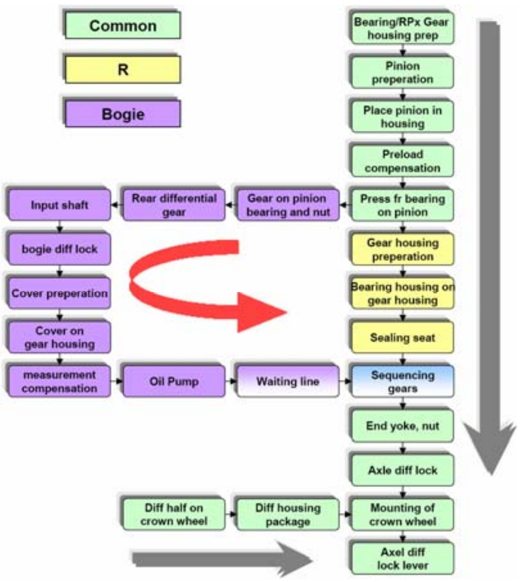


Figure 6.37 Bogie Cell Layout

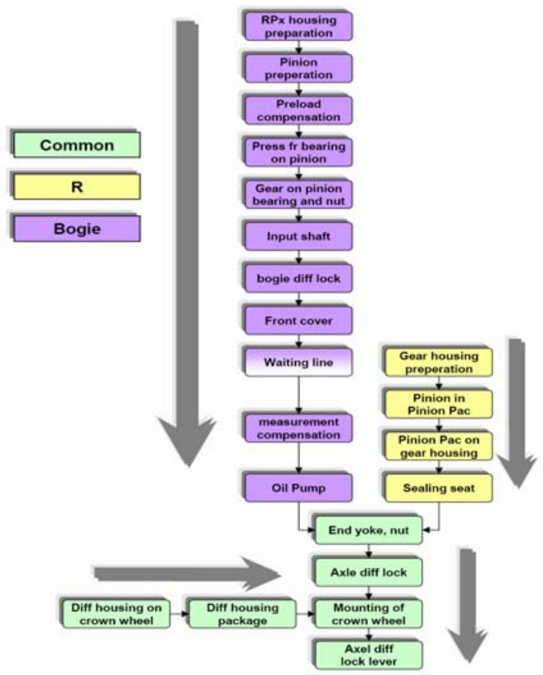


Figure 6.38 Layout with Pinion Pac

The assembly of the differential and crown wheel forms a separate flow (small grey arrow in figure 6.36) which joins the main flow at the station where the differential package is assembled to the gear housing. This flow has the same takt time as the main flow. Keeping this flow separate reduces total throughput time and reduces the length of the assembly line. Furthermore, there is no need for a fixture where the central gear can be transported and the differential package assembled simultaneously. It is also possible to use the current differential assembly lines keeping the total investment costs down.

7.6.3 Assembly line layout Pinion Pac

When the Pinion Pac is introduced the layout changes, see attachment O.3 and figure 6.38. This eliminates almost all waiting waste generated by the differences of the central gear. The Pinion Pac allows us to separate the RPx gears completely from the R- gears initially (Purple and Yellow blocks in figure 6.38) which mean that they will create minimal disturbances on each other. One can say that the RPx-gears are pre-assembled and then join the main flow. This makes the sequencing of the gears easier since the bogie- gears are assembled until they reach a waiting line (The purple and white block in figure 6.38). From this waiting line all gears are assembled in the same sequence as the rear axles creating a levelled flow and a consumption controlled production is facilitated. Using variant stations, one position performs one set of operations when an R- gear is to be assembled and another set of operations when a RBP- gear comes along. The operations to be performed before and after the waiting line can be adjusted to adapt the balancing to the R- gears assembly time.

7.7 Line balancing

We have performed a line balancing for the following assembly lines:

- v5 with current methods
- Bogie Cell with current methods
- Bogie Cell with new methods
- Bogie Cell with new methods and product alterations
- Bogie Cell with new methods, product alterations and Pinion Pac

The results of the line balancing have been compared to the staff size of today and the estimated size of the SLA-project if it where to be implemented in Falun. The analogy to the current staffing can be a bit misleading since there are part time operators included in the total number and some of the workers today also have logistical functions. In our and the SLA-proposal the workers only have assembly tasks. Detailed balancing schemes are described in attachment Q. Note that one operator assembling differential locks is not displayed in the balance schemes but included in the number of operators needed. In table 6.3 the staffing for all proposals and capacity steps are shown.

7.7.1 v5 with current methods

The line balance clearly shows that a strict one piece flow is not a very rational solution for the Scania central gears. There is close to 20 minutes of waiting waste for all the R and RP central gears (85% of all central gears produced) which represent approximately 40% of the throughput time. The staffing matrix in table 6.3 also show that this layout require more resources then the other proposals. Some of the waiting waste could probably be eliminated with a flexible working system and automation of some bogie operations but this requires further investigation

Assembly line staffing matrix per shift	Step 0	Step 1	Step 2	Step 3
CVX and RPX today	24			
SLA-Project	15	19		
V5 current methods	17	23	26	31
Bogie Cell current methods	14	18	21	23
Bogie Cell new methods	13	17	19	21
Bogie Cell new methods and prod. alterations	11	15	16	18
Bogie Cell new methods, prod. Alt and Pinion Pac	10	13	15	17

Table 6.3 Assembly line staffing matrix

7.7.2 Bogie Cell with current methods

This balancing uses one new method, the Projecta Set for the pinion assembly. The reason for including this method is that without it the assembly sequence would not be possible. This method reduces the assembly time and therefore the Bogie cell line has one operator less then the SLA-project. If this method was to be used in the SLA-project it would probably also reduce its number of operators by one. This balancing gives us a reference point in order to assess the effects of new methods and product alterations. We can also see that the layout is not creating waste in the form of transportation and movement. There are a number of bottlenecks that create balancing losses. The two largest are related to the crown wheel backlash, both the adjusting and the control. In step 0 there is also a loss of over 100 seconds at the last position in the main assembly line. This is a loss which is hard to eliminate. One way is to distribute it between the other positions or to have a quality control at the end of the line. In step 3 there is a 15 second overload for the last worker in the differential assembly. This could be solved letting an operator from the main assembly line perform these 15 seconds of work.

7.7.3 Bogie Cell with new methods

This balance uses all the new methods proposals. With all our proposed method changes the number of workers needed is 12 per shift instead of 15 for the SLA proposal or a 20 % reduction of personnel. Not to mention the quality improvements. The backlash bottlenecks have been partially removed by the rotary encoder method. One worker is shared between the differential assembly and the main assembly flow in Step 2, this is highlighted with a strong green colour in the balancing scheme. The andon worker performs the last 6 minutes of the bogie assembly in step 1. This is because it would create too much time and waiting waste if a worker was to be assigned to these specific operations. The overload for the differential assembly in step 3 still remains.

7.7.4 Bogie Cell with new methods and product alterations

Just as the title says this balancing analysis is based on the new methods from the previous analysis combined with the suggested product alterations. This is where time is saved. First of all the layout of the line is different as described in chapter 6.6. The integrated crown wheel and differential housing alone reduce the number of workers by two. In step 0 the number of operators is reduced by 33% compared to the single line project and in Step 3 the number of operators is less than step 1 with today's assembly line. This means that by gradually changing the product there will be no need to change the size of the workforce even though the output volumes will change. There are some balancing losses. The largest is at the end of the main assembly line in step 1 and 2. The losses in the differential assembly have been used to perform some operations in the main assembly line. These operations are marked with a strong green colour in the schemes in attachment P.

7.7.5 Bogie cell with Pinion Pac

As seen in figure 6.37 using the Pinion Pac increases the flexibility of the assembly line layout making it easier to adapt, balance and construct, it also reduces an additional worker.

8 Results and Conclusions

8.1 Assembly line staffing and balancing

Table 6.3 shows the staffing needs for the different proposals. The central gear assembly is currently employing two shifts and there will be no change of this in the near future. The staffing necessities per day are therefore the double of what is shown in Table 6.3. All proposals include one andon worker. All proposals also include a worker for the differential lock pre- assembly. The v5 proposal has one worker for the input shaft pre- assembly. The table clearly shows that having a straight unbroken flow, as the V5 proposal, requires far more operators as it induces waste and consume unnecessary resources as discussed earlier. It should be noticed that the staffing need is reduced for both the SLA-project and our proposals in comparison with today's assembly lines without investments in better methods. This is the result of a more efficient assembly flow where mainly waste of handling has been minimised.

It is clear that the largest reduction of personnel can be achieved by making the design of the gear more adapted to the assembly process. The new methods also contribute to reducing the number of workers needed but the real benefits of the new methods are the quality improvements, less rework and shorter throughput time.

In table 7.1 one can see the theoretical staffing matrix. This theoretical staffing matrix is the total assembly time needed for a product divided by the takt time and it tells us how many assembly positions that would be necessary with an ideal line balance. By comparing these theoretical numbers to those obtained from the line balancing you get an idea of the balancing losses.

Theoretical staffing matrix	**Step 0**	**Step 1**	**Step 2**	**Step 3**
v5	13,9	19,5	22,7	25,8
Bogie Cell	11,0	15,4	18,2	20,4
Bogie Cell new methods	10,5	14,7	17,3	19,4
Bogie Cell new methods and Product alterations	8,4	11,8	13,8	15,6
Pinion Pac	7,5	10,5	12,4	13,9

Table 7.1 Theoretical staffing matrix

Percentual balancing losses	**Step 0**	**Step 1**	**Step 2**	**Step 3**
v5	18%	15%	16%	17%
Bogie Cell	21%	14%	14%	11%
Bogie Cell new methods	19%	14%	9%	8%
Bogie Cell new methods and Product alterations	23%	21%	13%	13%
Pinion Pac	23%	19%	17%	18%

Table 7.2 Balancing losses

Table 7.2 shows the balancing losses in percent, which all are in the range of 10-20%. This is quite normal for assembly lines. However we did not expect two proposals with product alterations to have greater losses than the other two bogie cell options. One would expect the balancing losses to be reduced when bottlenecks are removed and the time for each operation lowered. This could of course also be a random coincidence. A way to reduce balancing losses is to shorten the assembly time of the operations or to break the operations down into smaller pieces. Shorter operations are easier to move between two positions making the balancing task more flexible and thus reducing the balancing losses.

8.2 Quality assurance strategy

In addition to the proposed methods and product alterations which prevent that errors are made all assembly equipment are connected to a Poka-Yoke system. The system signals the operator if an operation has not been performed according to specifications (e.g. if a screw has not been screwed with correct torque). The gear cannot leave the station until the operation has been performed accurately. The system provides information to the operator in real time, so that the fault can be dealt with immediately. The system also stores the assembly data needed, the operator is never to type a result manually. The system keeps track of the products and related specific data. The system then provides each workstation with the necessary information when needed.

If an operator detects a problem he or she can signal the system, bringing the whole assembly line to a halt so that the problem can be dealt with. In order to visualise that a problem has occurred and bring attention to people who can assist an andon signal should be used see figure 3.2. Halting the whole assembly line and visualising problems are enablers of continuous improvements, as every problem has to be dealt with as soon as it occurs.

8.3 Implementation time plan

Since the assembly methods are developed by the production department (DFEA) in Falun and the product design by the construction department (NAX and NAQ) in Södertälje we have chosen to provide two separate time plans; one for the methods and one for the product alterations.

8.3.1 Implementation plan for the new assembly methods

For the implementation plan for the new assembly methods, we propose that no more than two methods are implemented in parallel. This is because the resources are limited and if new methods are introduced gradually complications are easily identified and the working personnel will have time to adapt and learn about the new methods before another one is introduced. The Pinion Pac will be developed by Timken and is therefore not included. A diagram of the implementation plan is displayed in table 7.3.

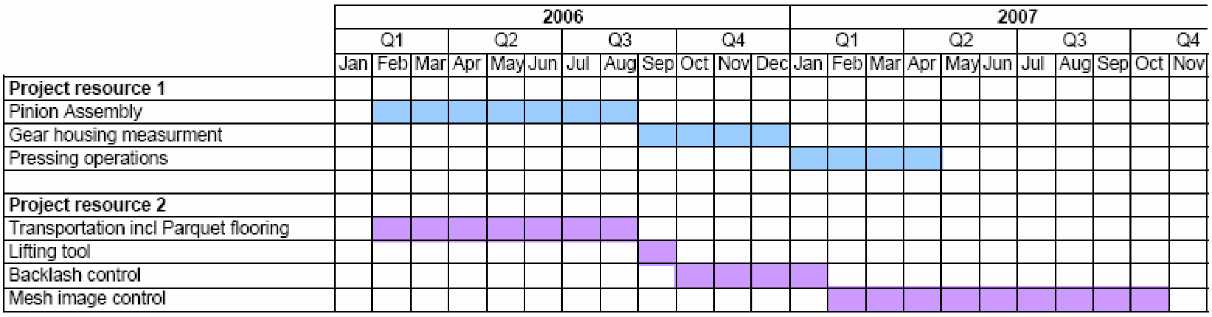


Table 7.3 Implementation plan diagram

Since it is said that a single line assembly flow is to be implemented this summer (2006) we have placed the two, according to us, most important investments first since they are essential for a takted, one- piece production flow. These two are the Timken Projecta Set method and the transportation of the gear. As stated earlier a new method for setting the preload is necessary in order to have a one piece production flow with as little rework as possible. A new transportation system is needed if one is to remove the assembly pallets described in attachment B, and to be able to perform all operations with the gear in line.

Once these two projects are completed we suggest that the triangular laser measurement method is implemented along with the lifting tool. The reasons are that the measuring method is important for the gear quality and for reducing the amount of rework in the assembly line. The lifting tool is a very simple and easy tool to develop which makes it possible to make eventual adjustments to the transportation or Projecta Set method as complications may arise without disturbing the development of new methods.

The development and construction of the lifting tools does not take much time so once they have been implemented the rotary encoder for the backlash control should be next. This is also done quite rapidly because all that is necessary is software programming and a fixture for the measuring device.

Now there are two assembly methods remaining. The pressing tools and the mesh image control. The pressing tools should be implemented since they will eliminate a lot of assembly time with a relatively small investment. The CCD- camera described in chapter 6.1.2.3 is a very accurate method but the investment is large and the pay- back time long. This option should be studied carefully and we have doubts if it will be profitable in the end. However we find this method so interesting that we include it in our final proposals anyway.

8.3.1.1 Investment estimate and cash flow for all method proposals

Attachment O shows two cash flow tables that shows the development of the investments over a ten year period if our proposed implementation plan is followed. The reason for having two cash two tables is to show that the mesh image proposal increase the total pay back time from 3 to 4 years. The positive effects of this method do not appear until year 8 which make any investments in the method highly questionable.

Looking at the second table without the mesh image control method in attachment O, one can see that the total pay back time is 3 years and that the total investment for all method proposals (except transportation, mesh image and Pinion Pac) is 217000 EUR. This is an investment sum that we find realistic for Scania and according to our calculations, will generate a profit of 100% after less then five years.

8.3.1.2 Recommended work procedure

The new assembly line concept should be implemented step by step. Therefore it is important not to try to do everything at once but to introduce one change, educate those affected by it, making sure it works properly and then start working on the next method.
We therefore suggest that, initially, only the R- gears are assembled in the new assembly line, while keeping the RPX running as it does today. This allows the bogie cell to be constructed once the main flow of the new line is working.

8.3.2 Implementation plan for product alterations

Following the analysis in chapter 6.4, the product alterations have been divided into three different groups defined by their complexity and development time. In table 7.4 the annual savings that can be made by each product alteration where this is measurable.

	Main flow		**Bogie cell flow**		
	Time savings	Cost savings	Time savings	Cost savings	Total savings
Short term					
Steering pin input differential	0	0	126	10059	**10059**
Integrate screws with washer	25	13972	37	2954	**16925**
Screw for adj. Diff. Lock	25	13972	60	4790	**18762**
Long term					
Threaded lid for input shaft	0	0	300	23951	**23951**
Collapsible spacer	44	24590	0	0	**24590**
Integrating diff lock	20	11177	20	1597	**12774**
Integrate differential crown wheel	287	160393	0	0	**160393**

Table 7.4 Expected annual savings of product alterations (EUR)

Short term – Simple alterations, little development time and relative low investment costs.

- Screw for adjusting differential lock
- Integrating washers with screws
- Eliminate steering pins for input shaft differential

Long term – more complex changes that require extensive design changes.

- Collapsible sleeve for pinion preload setting
- Integrating differential housing and crown wheel
- Adjustable spacer for input shaft
- Differential lock manoeuvring unit integrated in gear housing
- Conical gear set manufactured with grinding method
- Oil filter RB662

Next generation – Changes meant for the next generation of central gears.

- Bearings in X-configuration
- Threaded lid for input shaft

- Straight lever for the differential lock
- Integrating coupling half with differential housing half

The following group are the product alterations that have been discarded, together with the main reason for being discarded:

- Pinion Pac – high cost
- Chamfers for washers - integrating screws and washers is a better alternative
- Two piece bearing housing – a method which makes rework redundant should be invested in instead
- Same bolts for crown wheel and differential housing - integrating differential housing and crown wheel is a better alternative

8.4 DFAA- analysis with product alterations

Here is a summary of a DFAA-analysis of the central gears if they had the following product alterations (for detailed result see Attachment H.3):

R-gears:

- Collapsible spacer
- Integrated differential lock
- Washers integrated with screws
- Crown wheel integrated with differential housing half
- Straight differential lock lever
- Screw for adjusting differential lock

Bogie gears: Same alterations as for the R-gears and in addition:

- Input shaft steering pins removed
- Threaded lid for the input shaft
- Re-designed oil filter

With regard to the problems stated in chapter 6.3, the most noticeable difference is that the number of parts has been reduced. The only module that is considered to have an unacceptable number of parts is the differential, mainly due to need for a strong screw union between the differential housing halves. The number of 1:s scored in total for all gears in the modular level has been reduced from five to two (The two remaining are due to the number of parts in the differential). In the detail level the number of 1:s has been reduced from 32 to

12 for the R-gears and from 52 to 13 for the Bogie gears. This means elimination of 63% of the most serious design problems for the R- gears and 75% for the Bogie gears. These results are mainly due to the fact that many of the parts that scored low in the initial anaylsis have been eliminated or integrated. One should notice that comparing the DFA-index from before and after analysis should be done with caution. Some parts that scored high and acted as counterweight to the parts that scored low, are no longer necessary if the product alterations are made. Therefore the DFA-index is in some cases lower in the latter analysis than in the analysis of today’s central gears.

9 Discussion

9.1 Lean production and SPS

This entire thesis is based on the theories of lean production. Lean production has proven itself to be a great if not the best way for an organisation to cut costs and minimize waste. But is lean production the solution for all organisations? Does lean production have any drawbacks or flaws?

9.1.1 Problems with lean and pull systems

Eliminating buffers and inventory from a manufacturing system reduces cost and bound capital but it makes the system more sensitive to disturbances. In a mass production system with large buffers and inventories a machine breakdown may not affect the entire process at all since the other processes can maintain production with the available inventory. In an ideal lean system a machine breakdown stops the entire production chain with high costs as a result.

The sensitivity of lean production systems is seen as a weakness by some and as a strength by others. Therefore it is important to know what results one expects from the production process before implementing a lean system with small or no buffers and inventory (Ståhl 2005).

9.1.2 Other aspects of the Japanese productivity

The impression that the production system is the fundamental key to the worldwide Japanese success is easily perceived. However there are two other aspects that have a great effect on productivity and quality (Berggren 2005). These are:

The design of the products. The most important aspect of high productivity is that the product is easy to produce, that it is designed for assembly. At least 50% of the Japanese productivity advantage is estimated to originate in products designed for assembly (Berggren 2005). We have earlier in this thesis concluded that the Scania central gears are not designed for assembly.

Selection of personnel. While in Europe and North America assembly personnel are often hired without any extensive interviews or tests the Japanese organizations uses tests of IQ, dexterity, ambition and creativity combined with interviews and role playing. The result is that is an achievement- orientated workforce competing not only as a group but also as individuals for their personal ambitions. To accomplish this the ratio between applicants and the number of job opportunities needs to be great (Berggren 2005). This is not very likely in a small city as Falun.

9.1.3 The situation for the workers

Lean assembly often aims at breaking down each assembly operations in small parts in order to divide them between different assembly positions. This makes the work at each position less complicated and easier to learn for the workers but it also removes stimulating challenges in the work and the tasks becomes more monotone and boring. The use of flexible hours or overtime to compensate for fluctuations in demand or earlier production stops causes overtime to be ordered with very short notice. There is no possibility for an assembler to work faster for a period of time ("work up the line") in order to create an unofficial break to go to the bathroom or sit down a minute. These factors create stress for the workers and they tend to feel abused (Post & Slaughter 2006).

During our interviews with assembly personnel currently working at takted Scania assembly lines we got the impression that these matters are of no great concern, and are easy to get used to. The assembly personnel feel that they always know the pace at which they have to work and that the takt time and balancing allows them to work at a comfortable pace.

9.1.4 The situation for the suppliers

There is a contradiction in the literature on lean production regarding the Japanese productivity wonder. While the major producers as Toyota, Mazda, Sony etc enjoy high productivities and profits the small suppliers suffer and are working on the edge of what is possible. These are the ones that suffer from cutting cost and reducing inventory (Sandkull & Johansson 2000).

9.1.5 The effect on the environment

As organisations reduce their inventories, buffers, batches, shipments, lead times etc. the demand for transporting goods in smaller batcher with shorter intervals increase. Lean production therefore has a negative effect on traffic congestion and pollution (Berggren 2005). Since there are no safety nets in the material supply it is not unusual that companies such as Scania ship one or just a few parts hundreds of kilometres in order to keep the assembly lines moving.

9.2 DFAA

We found DFAA to be an efficient method of finding problem areas which hinder rational assembly. However DFAA has some flaws. The method comprises a number of design rules, but provides no support on how to prioritise these rules. In addition, the different criterions are not weighted. As an example a part can score a 1 on two different criterions, which may have different effects in the assembly process.

9.3 Future research

When designing an assembly line many aspects must be taken into consideration. Here are some recommendations on how Scania should proceed with the findings in this project.

9.3.1 Assembly methods

Many of the assembly methods presented in this report have not been tested by us, and should be evaluated more thoroughly before any investments are done. In some cases we have had to rely on information provided by suppliers and from patents, which is the case for e.g. TIMKEN's Projecta Set. The suppliers are of course very interested in selling their products. Therefore it is necessary to test the methods we have proposed or alternatively have the supplier to arrange some sort of demonstration or visiting a manufacturer who uses the product today to hear their point of view.

There are some areas where we have failed to find better methods. An example is a better method for preloading the input shaft's bearings. The method gives a good result, but is far too time consuming. This is an area that should be investigated in the future.

9.3.2 Product alterations

As focus on assembly aspects have formed the base for the proposed product alterations, other aspects such as development and manufacturing costs should be taken into consideration too. This is to guarantee that the product alterations enable lower overall costs than today.

9.3.3 Workstation design

This is an important issue that has not been addressed to any further extent when presenting assembly line layouts. We recommend Scania to use the theoretical framework for good ergonomics that is presented in this report when designing the workstations in the future.

9.3.4 Information System

The assembly line we have proposed requires a system that manages the internal sequence in the assembly line, and ensures that the gears leave the assembly line in the same sequence as the axle assembly lines. This may prove to be complicated to implement, however it is necessary if all gear types are to be assembled rationally in one line. We have also stated in this report that all measurement data is to be stored and handled by an information system, and that a Poka-Yoke system governs the assembly processes. The system requirements, development costs and feasibility have not been addressed in this report. These matters are important to investigate as they may have a great impact on the total investment cost.

9.3.5 Time studies

It must be kept in mind that time studies and line balancing for the proposals has been based on assumptions of the performance of untested methods and product alterations. We suggest that Scania perform simulations and optimization calculations for the assembly lines in the future to validate and further enhance the results of this report.

9.4 Critical review

9.4.1 Our prerequisites

When we started working on this thesis none of us had any hands on experience of working with lean production, design for assembly or competitive benchmarking. We can therefore not reflect or compare our results to earlier experiences.

9.4.2 Theoretical framework

SPS is developed by Scania and it has been the starting point for the thesis. Our theoretical foundation was therefore decided before we started working. We did not search for other production systems to compare the Scania production system against. On the other hand we did not feel that this was necessary since Scania today has some of the most efficient assembly lines in Europe.

9.4.3 Complicating factors

The central gear design departments NAX and NAQ are situated at the Scania headquarters in Södertälje, Sweden. The distance between Falun and Södertälje (300 km) has made it hard for us to discuss our product alterations with the design engineers. The correspondence has consisted in e- mails, phone calls and three visits to Södertälje. Still we have not had the day to day interaction with the people in Södertälje as we have had with the production engineers in Falun. If the development department had been situated in Falun or the assembly lines in Södertälje, we might have been able to investigate our product alterations in more detail.

It was hard for us to arrange visits to other productions sites such as BMW- Munich, Haldex-Landskrona, MAN- Munich, Saab- Södertälje etc. The reasons have varied. But mostly we have been told that there has not been enough recourses to show us around for an entire day. For the larger German manufacturers it was very hard just to establish contact with the relevant employee. These potential visits would probably have raised the level of the thesis and added to the number of assembly methods and product alterations generated.

9.4.4 Things that could have been done differently

It would have been very helpful if we would have had a list of current assembly problems and why they are problems. One example is the R- gear housing measurement. We did not realise that this was a problem or that it needed to be measured until 6 or 7 weeks into the project.

We should have waited with the line layout and balancing until we had generated a larger number of assembly methods and product alterations. During the writing of this thesis the layout has been changed many times mostly because of the discovery of a new assembly line method or product alteration.

A more in- depth and detailed study of the current assembly lines could have been done in order to measure the results of the changes more accurately.

10 Conclusions

In conclusion we have shown that there are many possibilities for Scania to improve their central gear assembly lines in order to make them more efficient.

In order to reach a one piece flow a new method for setting the bearing preload and measuring the gear housing is necessary, if no actions are taken in these two areas any further improvements will have little or no effect on the efficiency of the production system.

The design for assembly study showed a number of weaknesses and areas of improvement for the central gears. It also indicated that many parts can be integrated or eliminated without any major investments. This fact is also clear when looking at similar products, the Getrag High Torque gear in particular.

The benchmarking studies showed that Scania has the most complex and outdated products on the market. This can however be rectified with small means following some of the advice presented in this report.

The assembly line layout denominated “Bogie cell” enables a more rational product flow, possibilities to have a takt time and better supervision of the production then the current layout.

The investment estimates show that the majority of the changes can be implemented with a pay- back time of less then 2 years. In order to implement all the changes proposed it is important to have a long term perspective and not to only look at the economical benefits but also the health and quality improvements which will reduce costs that are difficult to identify and improve Scania’s image and brand.

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